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ELEMENTARY TREATISE

ON

PHYSICS

EXPERIMENTAL AND APPLIED

FOR THE USE OF COLLEGES AND SCHOOLS.

TRANSLATED AND EDITED FROM

GANOT'S ÉLÉMENTS DE PHYSIQUE

(*with the Author's sanction*)

BY

E. ATKINSON, PH.D., F.C.S.

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TO

THE SIXTH EDITION.

To THE PRESENT EDITION three coloured plates and twenty-five illustrations have been added; of which twenty-one are entirely new, and the others are substituted for former ones.

The additions to the text amount to thirty pages. In making these additions, while the wants of the general reader have been attended to, the principal aim has been, as in former editions, to render the book more useful for the student of Physical Science. Accordingly, as regards new matter, the main additions have been in those subjects which are calculated to take a permanent place in elementary instruction.

I take this opportunity of expressing my obligation to Dr. MARTIN, of Christ's College, Cambridge, for having revised, and in great measure rewritten, those parts of the present edition which refer to Physiological Electricity.

STAFF COLLEGE: *June* 1873.

TRANSLATOR'S PREFACE

TO

THE FIRST EDITION.

THE *Éléments de Physique* of Professor GANOT, of which the present work is a translation, has acquired a high reputation as an Introduction to Physical Science. In France it has passed through Nine large editions in little more than as many years, and it has been translated into German and Spanish.

This reputation it doubtless owes to the clearness and conciseness with which the principal physical laws and phenomena are explained, to its methodical arrangement, and to the excellence of its illustrations. In undertaking a translation, I was influenced by the favourable opinion which a previous use of it in teaching had enabled me to form.

I found that its principal defect consisted in its too close adaptation to the French systems of instruction, and accordingly, my chief labour, beyond that of mere translation, has been expended in making such alterations and additions as might render it more useful to the English student.

I have retained throughout the use of the centigrade thermometer, and in some cases have expressed the smaller linear measures on the metrical system. These systems are now everywhere gaining ground, and an apology is scarcely needed for an innovation which may help to familiarise the English student with their use in the perusal of the larger and more complete works on Physical Science to which this work may serve as an introduction.

E. ATKINSON.

ROYAL MILITARY COLLEGE, SANDHURST.

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ELEMENTARY TREATISE

ON

PHYSICS.

BOOK I.

ON MATTER, FORCE, AND MOTION.

CHAPTER I.

GENERAL NOTIONS.

1. **Object of Physics.**—The object of *Physics* is the study of the phenomena presented to us by bodies. It should, however, be added, that changes in the nature of the body itself, such as the decomposition of one body into others, are phenomena whose study forms the more immediate object of *chemistry*.

2. **Matter.**—That which possesses the properties whose existence is revealed to us by our senses, we call *matter* or *substance*.

All substances at present known to us may be considered as chemical combinations of sixty-five elementary or *simple* substances. This number, however, may hereafter be diminished or increased by a more powerful chemical analysis.

3. **Atoms, Molecules.**—From various properties of bodies we conclude that the matter of which they are formed is not perfectly continuous, but consists of an aggregate of an immense number of exceedingly small portions or *atoms* of matter. These atoms cannot be divided physically, they are retained side by side, without touching each other, being separated by distances which are great in comparison with their supposed dimensions.

A group of two or more atoms forms a *molecule*, so that a body may be considered as an aggregate of very small molecules, and these again as aggregates of still smaller atoms. The smallest masses of matter we ever obtain artificially are *particles* and not molecules or atoms. Molecules retain their position in virtue of the action of certain forces called *molecular forces*.

From considerations based upon various physical phenomena Sir W. Thomson has calculated that in ordinary solids and liquids the average distance between contiguous molecules is less than the hundred millionth and greater than the two thousand millionth of a centimètre.

To give an idea of the degree of the size of the molecules Sir W. Thomson gives this illustration: 'Imagine a drop of rain, or a glass sphere the size of a pea, magnified to the size of the earth, the molecules in it being increased in the same proportion. The structure of the mass would then be coarser than that of a heap of fine shot, but probably not so coarse as that of a heap of cricket-balls.'

4. **Molecular state of bodies.**—With respect to the molecules of bodies three different states of aggregation present themselves.

First, the solid state, as observed in woods, stones, metals, etc., at the ordinary temperature. The distinctive character of this state is, that the relative positions of the molecules of the bodies cannot be changed without the expenditure of more or less force. As a consequence, solid bodies tend to retain whatever form may have been given to them by nature or by art.

Secondly, the liquid state, as observed in water, alcohol, oil, etc. Here the relative position of the molecules is no longer permanent, the molecules glide past each other with the greatest ease, and the body assumes with readiness the form of any vessel in which it may be placed.

Thirdly, the gaseous state, as in air. In gases the mobility of the molecules is still greater than in liquids; but the distinctive character of a gas is its incessant struggle to occupy a greater volume, or the tendency of its molecules to recede from each other.

The general term *fluid* is applied to both liquids and gases.

We shall see in the sequel that the state of a body depends upon the relations which exist between its molecular attractions and repulsions, and that for one and the same body these relations vary with the temperature. On this account most simple bodies, and many compound ones, may be made to pass successively through all the three states. Water presents the most familiar example of this.

5. **Physical phenomena, laws, and theories.**—Every change which can happen to a body, mere alteration of its chemical constitution being excepted, may be regarded as a *physical phenomenon*. The fall of a stone, the vibration of a string, and the sound which accompanies it, the rippling of the surface of a lake, and the freezing of water, are examples of such phenomena.

A *physical law* is the constant relation which exists between any phenomenon and its cause. As an example, we have the phenomenon of the diminution of the volume of a gas by the application of pressure; the corresponding law has been determined, and is expressed by saying that the volume of a gas is inversely proportional to the pressure.

In order to explain whole classes of phenomena suppositions or *hypotheses* are made use of; the utility and probability of an hypothesis or theory is the greater the simpler it is, and the more varied and numerous are the phenomena which are *explained* by it; that is to say, are brought into regular causal connection among themselves and with other natural phenomena. Thus, the adoption of the undulatory theory of light is justified by the simple and unconstrained explanation it gives of all luminous phenomena, and by the connection it reveals with the phenomena of heat.

6. **Physical agents.**—In our attempts to ascend from a phenomenon to its cause, we assume the existence of *physical agents*, or *natural forces*, acting upon matter; as examples of such we have *gravitation*, *heat*, *light*, *magnetism*, and *electricity*.

Since these physical agents are disclosed to us only by their effects, their intimate nature is completely unknown. In the present state of science, we cannot say whether they are properties inherent in matter, or whether they result from movements impressed on the mass of subtile and imponderable forms of matter diffused through the universe. The latter hypothesis is however generally admitted. This being so it may be further asked are there several distinct forms of imponderable matter, or are they in reality but one and the same? It would seem that the latter opinion tends to prevail as the physical sciences extend their limits. In accordance with this hypothesis these subtile forms of matter are spoken of as *imponderable fluids*, since their weight is inappreciable by the aid of the most delicate balances. Hence arises the distinction sometimes made between *ponderable matter*, or matter properly so called, and *imponderable matter*, or physical agents.

The term *incoercible* is also applied to these imponderable fluids, to express the impossibility of confining them in, or excluding them from any closed vessel, as we do air and other gases.

CHAPTER II.

GENERAL PROPERTIES OF BODIES.

7. **Different kinds of properties.**—By the term *properties* as applied to bodies, we understand the different ways in which bodies present themselves to our senses. We distinguish *general* from *specific* properties. The former are shared by all bodies, and amongst them the most important are *impenetrability*, *extension*, *divisibility*, *porosity*, *compressibility*, *elasticity*, *mobility*, and *inertia*.

Specific properties are such as are observed in certain bodies only, or in certain states of these bodies; such are *solidity*, *fluidity*, *tenacity*, *ductility*, *malleability*, *hardness*, *transparency*, *colour*, etc.

With respect to the above general properties, it may be remarked that *impenetrability* and *extension* might be more aptly termed essential attributes of matter, since they suffice to define it; and that divisibility, porosity, compressibility, and elasticity, do not apply to atoms, but only to bodies or aggregates of atoms (3).

8. **Impenetrability.**—*Impenetrability* is the property in virtue of which

two portions of matter cannot, at the same time, occupy the same portion of space.

Strictly speaking, this property applies only to the atoms of a body. In many phenomena bodies appear to penetrate each other; thus, the volume of a compound body is always less than the sum of the volumes of its constituents; for instance, the volume of a mixture of water and sulphuric acid, or of water and alcohol, is less than the sum of the volumes before mixture. In all these cases, however, the penetration is merely apparent, and arises from the fact that in every body there are interstices or spaces unoccupied by matter.

9. **Extension.**—*Extension* or *magnitude* is the property in virtue of which every body occupies a limited portion of space.

Many instruments have been invented for measuring linear extension or lengths with great precision. Two of these, the vernier and micrometer screw, on account of their great utility, deserve to be here mentioned.

10. **Vernier.**—The *vernier* forms a necessary part of all instruments where lengths or angles have to be estimated with precision; it derives its name from its inventor, a French mathematician, who died in 1637, and consists essentially of a short graduated scale, *ab*, which is made to slide along a fixed scale, AB, so that the graduations of both may be compared with each other. The fixed scale, AB, being divided into equal parts, the whole length of the vernier, *ab*, may be taken equal to nine of those parts, and itself divided into ten equal parts. Each of the parts of the vernier, *ab*, will then be less than a part of the scale by one tenth of the latter.

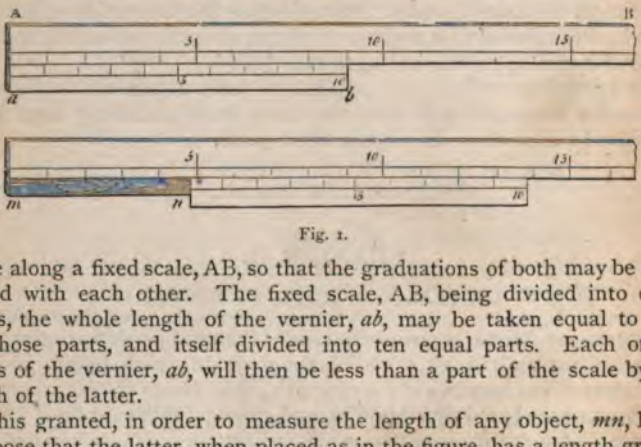

Fig. 1.

This granted, in order to measure the length of any object, *mn*, let us suppose that the latter, when placed as in the figure, has a length greater than four but less than five parts of the fixed scale. In order to determine by what fraction of a part *mn* exceeds four, one of the ends, *a*, of the vernier, *ab*, is placed in contact with one extremity of the object, *mn*, and the division on the vernier is sought which coincides with a division on the scale, AB. In the figure this coincidence occurs at the eighth division of the vernier, counting from the extremity, *n*, and indicates that the fraction to be measured is equal to $\frac{8}{10}$ths of a part of the scale, AB. In fact, each of the parts of the vernier being less than a part of the scale by $\frac{1}{10}$th of the latter, it is clear that on proceeding towards the left from the point of coincidence, the divisions of the vernier are respectively one, two, three, etc., tenths behind the divisions of the scale ; so that the extremity, *n*, of the object (that is to say, the eighth division of the vernier) is $\frac{8}{10}$ths behind the division marked 4 on the scale ; in other words, the length of *mn* is equal to $4\frac{8}{10}$ths of the parts into which the scale AB is divided. Consequently, if the scale AB were divided into inches, the length of *mn* would be $4\frac{8}{10} = 4\frac{4}{5}$ inches. The divisions on the scale remaining the same, it would be necessary to increase the length of the vernier in order to measure the length *mn* more accurately. For instance, if the length of the vernier were equal to nineteen of the parts on the scale, and this length were divided into twenty equal parts, the length *mn* could be determined to the twentieth of a part on a scale, and so on. In instruments like the theodolite, intended for measuring angles, the scale and vernier have a circular form, and the latter usually carries a magnifier, in order to determine with greater precision the coincident divisions of vernier and scale.

11. **Micrometer screw.**—Another useful little instrument for measuring small lengths with precision is the *micrometer screw*. It is used under various forms, but the principle is the same in all, and may be illustrated by a simple example. Suppose the distance between the threads of an accurately cut screw to be equal to $\frac{1}{10}$th of an inch, and the head of the screw to be a tolerably large circle divided into one hundred equal parts. If the screw is fixed in such a manner that it can only turn on its axis, but neither advance nor recede, and if it work in a nut held between guides which prevent it from turning, then every turn of the screw will cause the nut to advance through the tenth part of an inch. If a fixed pointer be placed before the divided circle at the head of the screw, and the latter turned through so small an angle that only one division of the circle passes under the pointer, the hundredth part of a turn will have been given to the screw, and the nut thereby caused to advance or recede through the hundredth part of the distance between two threads—that is to say, through the $\frac{1}{1000}$th part of an inch. Applications of this principle to the measurement of small lengths are met with in the *spherometer*, and in the *dividing machine*, and will be readily understood when seen.

12. **Divisibility**—is the property in virtue of which a body may be separated into distinct parts.

Numerous examples may be cited of the extreme divisibility of matter. The tenth part of a grain of musk will continue for years to fill a room with its odoriferous particles, and at the end of that time will scarcely be diminished in weight.

Blood is composed of red, flattened globules, floating in a colourless liquid called *serum*. In man the diameter of one of these globules is less than the 3,500th part of an inch, and the drop of blood which might be suspended from the point of a needle would contain about a million of globules.

Again, the microscope has disclosed to us the existence of insects smaller even than these particles of blood ; the struggle for existence reaches even to these little creatures, for they devour still smaller ones.

If blood runs in the veins of these devoured ones, how infinitesimal must be the magnitude of its component globules !

Has then the divisibility of matter no limit? Although experiment fails to determine such limit, many facts in chemistry, such as the invariability in the relative weights of the elements which combine with each other, would lead us to believe that a limit does exist. It is on this account that bodies are conceived to be composed of extremely minute and indivisible parts called *atoms* (3).

13. **Porosity.**—*Porosity* is the quality in virtue of which interstices or *pores* exist between the molecules of a body.

Two kinds of pores may be distinguished : *physical pores*, where the interstices are so small that the surrounding molecules remain within the sphere of each other's attracting or repelling forces; and *sensible pores*, or actual cavities across which these molecular forces cannot act. The contractions and dilatations resulting from variations of temperature are due to the existence of physical pores, whilst in the organic world the sensible pores are the seat of the phenomena of exhalation and absorption.

In wood, sponge, and a great number of stones, for instance, pumice stone, the sensible pores are apparent; physical pores never are. Yet, since the volume of every body may be diminished, we conclude that all possess physical pores.

The existence of sensible pores may be shown by the following experiment :—A long glass tube, A (fig. 2), is provided with a brass cup, *m*, at the top, and a brass foot made to screw on to the plate of an air-pump. The bottom of the cup consists of a thick piece of leather. After pouring mercury into the cup so as entirely to cover the leather, the air-pump is put in action, and a partial vacuum produced within the tube. By so doing a shower of mercury is at once produced within the tube, for the atmospheric pressure on the mercury forces that liquid through the pores of the leather. In the same manner water or mercury may be forced through the pores of wood, by replacing the leather in the above experiment by a disc of wood cut perpendicular to the fibres.

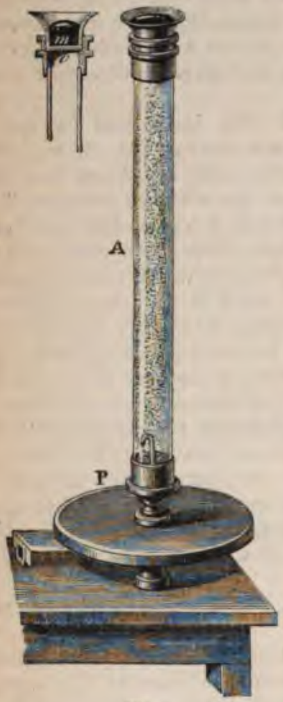

Fig. 2.

When a piece of chalk is thrown into water, air-bubbles at once rise to the surface, in consequence of the air in the pores of the chalk being expelled by the water. The chalk will be found to be heavier after immersion than it was before, and from the increase of its weight the volume of its pores may be easily determined.

The porosity of gold was demonstrated by the celebrated Florentine experiment made in 1661. Some academicians at Florence, wishing to try whether water was compressible, filled a thin globe of gold with that liquid, and, after closing the orifice hermetically, they exposed the globe to pressure with a view of altering its form, well knowing that any alteration in form must be accompanied by a diminution in volume. The consequence was, that the water forced its way through the pores of the gold, and stood on the outside of the globe like dew. More than twenty years previously the same fact was demonstrated by Francis Bacon by means of a leaden sphere, the experiment has since been repeated with globes of other metals, and similar results obtained.

14. **Apparent and real volumes.**—In consequence of the porosity of bodies, it becomes necessary to distinguish between their real and apparent volumes. The *real volume* of a body is the portion of space actually occupied by the matter of which the body is composed ; its *apparent volume* is the sum of its real volume and the total volume of its pores. The real volume of a body is invariable, but its apparent volume can be altered in various ways.

15. **Applications.**—The property of porosity is utilised in filters of paper, felt, stone, charcoal, etc. The pores of these substances are sufficiently large to allow liquids to pass, but small enough to arrest the passage of any substances which these liquids may hold in suspension. Again, large blocks of stone are often detached in quarries by introducing wedges of dry wood into grooves cut in the rock. These wedges being moistened, water penetrates their pores, and causes them to swell with considerable force. Dry cords, when moistened, increase in diameter and diminish in length, a property of which advantage is sometimes taken in order to raise immense weights.

16. **Compressibility.**—*Compressibility* is the property in virtue of which the volume of a body may be diminished by pressure. This property is at once a consequence and a proof of porosity.

Bodies differ greatly with respect to compressibility. The most compressible bodies are gases ; by sufficient pressure they may be made to occupy ten, twenty, or even a hundred times less space than they do under ordinary circumstances. In most cases, however, there is a limit beyond which, when the pressure is increased, they become liquids.

The compressibility of solids is much less than that of gases, and is found in all degrees. Cloths, paper, cork, woods, are amongst the most compressible. Metals are so also to a great extent, as is proved by the process of coining, in which the metal receives the impression from the die. There is, in most cases, a limit beyond which, when the pressure is increased, bodies are fractured or reduced to powder.

The compressibility of liquids is so small as to have remained for a long time undetected : it may, however, be proved by experiment, as will be seen in the chapter on Hydrostatics.

17. **Elasticity.**—*Elasticity* is the property in virtue of which bodies

resume their original form or volume, when the force which altered that form or volume ceases to act. Elasticity may be developed in bodies by pressure, by traction or *pulling*, flexion or *bending*, and by torsion or *twisting*. In treating of the general properties of bodies, the elasticity developed by pressure alone requires consideration; the other kinds of elasticity being peculiar to solid bodies, will be considered amongst their specific properties (arts. 79, 80, 81).

Gases and liquids are perfectly elastic; in other words, after undergoing a change in volume they regain exactly their original volume when the pressure becomes what it originally was. Solid bodies present different degrees of elasticity, though none present the property in the same perfection as liquids and gases, and in all it varies according to the time during which the body has been exposed to pressure. Caoutchouc, ivory, glass, and marblepossess considerable elasticity; lead, clay, and fats, scarcely any.

There is a limit to the elasticity of solids, beyond which they either break or are incapable of regaining their original form and volume. This is called the *limit of elasticity*. In sprains, for instance, the elasticity of the tendons has been exceeded. In gases and liquids, on the contrary, no such limit can be reached; they always regain their original volume.

If a ball of ivory, glass, or marble, be allowed to fall upon a slab of polished marble, which has been previously slightly smeared with oil, it will rebound and rise to a height nearly equal to that from which it fell. On afterwards examining the ball a circular blot of oil will be found upon it, more or less extensive according to the height of the fall. From this we conclude that at the moment of the shock the ball was flattened, and that its rebound was caused by the effort to regain its original form.

18. **Mobility, motion, rest.**—*Mobility* is the property in virtue of which the position of a body in space may be changed.

Motion and rest may be either relative or absolute. By the *relative motion* or *rest* of a body we mean its change or permanence of position with respect to surrounding bodies; by its *absolute motion* or *rest* we mean the change or permanence of its position with respect to ideal fixed points in space.

Thus a passenger in a railway carriage may be in a state of relative rest with respect to the train in which he travels, but he is in a state of relative motion with respect to the objects, such as trees, houses, etc., past which the train rushes. These houses again enjoy merely a state of relative rest, for the earth itself which bears them is in a state of incessant relative motion with respect to the celestial bodies of our solar system, inasmuch as it moves at the rate of more than eighteen miles in a second. In short, absolute motion and rest are unknown to us; in nature, relative motion and rest are alone presented to our observation.

19. **Inertia.**—*Inertia* is a purely negative property of matter; it is the incapability of matter to change its own state of motion or rest.

A body when unsupported in mid-air does not fall to the earth in virtue of any inherent property, but because it is acted upon by the force of gravity. A billiard ball gently pushed does not move more and more slowly, and finally stop, because it has any preference for a state of rest, but because its motion is impeded by the friction on the cloth on which it rolls, and by the resistance of the air. If all impeding causes were withdrawn, a body once in motion would continue to move for ever.

20. **Application.**—Numerous phenomena may be explained by the inertia of matter. For instance, before leaping a ditch we run towards it, in order that the motion of our bodies at the time of leaping may add itself to the muscular effort then made.

On descending carelessly from a carriage in motion, the upper part of the body retains its motion, whilst the feet are prevented from doing so by friction against the ground; the consequence is we fall towards the moving carriage. A rider falls over the head of a horse if it suddenly stops. In fixing the head of a hammer by striking the handle against the ground we have an application of inertia.

The terrible accidents on our railways are chiefly due to inertia. When the motion of the engine is suddenly arrested the carriages strive to continue the motion they had acquired, and in doing so are shattered against each other.

Hammers, pestles, stampers are applications of inertia. So are also the enormous iron fly-wheels, by which the motion of steam engines is regulated.

CHAPTER III.

ON FORCE, EQUILIBRIUM, AND MOTION.

21. **Measure of Time.**—To obtain a proper measure of force it is necessary, as a preliminary, to define certain conceptions which are presupposed in that measure; and, in the first place, it is necessary to define the unit of time. Whenever a *second* is spoken of without qualification it is understood to be a second of *mean solar time*. The exact length of this unit is fixed by the following consideration. The instant when the sun's centre is on an observer's meridian—in other words, the instant of the transit of the sun's centre—can be determined with exactitude, and thus the interval which elapses between two successive transits also admits of exact determination, and is called an *apparent* day. The length of this interval differs slightly from day to day, and therefore does not serve a convenient measure of time. Its *average* length is free from this inconvenience, and therefore serves as the required measure, and is called a *mean solar day*. The short hand of a common clock would go exactly twice round the face in a mean solar day if it went perfectly. The mean solar day consists of 24 equal parts called *hours*, these of 60 equal parts called *minutes*, and these of 60 equal parts called *seconds*. Consequently, the second is the 86,400th part of a mean solar day, and is the generally received unit of time.

22. **Measure of Space.**—Space may be either *length* or *distance*, which is space of one dimension; *area*, which is space of two dimensions; or

volume, which is space of three dimensions. In England the standard of length is the British Imperial Yard, which is the distance between two points on a certain metal rod, kept in the Tower of London, when the temperature of the whole rod is 60° F. = 15°·5 C. It is, however, usual to employ as a unit, a *foot*, which is the third part of a yard. In France the standard of length is the *mètre*; this is approximately equal to the ten-millionth part of a quadrant of the earth's meridian, that is of the arc from the Equator to the north pole; it is practically fixed by the distance between two marks on a certain standard rod. The relation between these standards is as follows:

1 yard = 0·914383 mètre.
1 mètre = 1·093633 yard.

The unit of length having been fixed, the units of area and volume are connected with it thus: the *unit of area* is the area of a square, one side of which is the unit of length. The *unit of volume* is the volume of a cube, one edge of which is the unit of length. These units in the case of English measures are the square yard (or foot) and the cubic yard (or foot) respectively; in the case of French measures, the square mètre and cubic mètre respectively.

23. **Measure of Mass.**—Two bodies are said to have equal masses when, if placed in a perfect balance *in vacuo*, they counterpoise each other. Suppose we take lumps of any substance, lead, butter, wood, stone, etc., and suppose that any of them when placed on one pan of a balance will exactly counterpoise any other of them when placed on the opposite pan—the balance being perfect and the weighing performed *in vacuo*; this being the case, these lumps are said to have equal masses. That these lumps differ in many respects from each other is plain enough; in what respects they have the same properties in virtue of the equality of their masses is to be ascertained by subsequent enquiry.

The British unit of mass is the standard pound (avoirdupois), which is a certain piece of platinum kept in the Exchequer Office in London. This unit having been fixed, the mass of a given substance is expressed as a multiple or submultiple of the unit.

It need scarcely be mentioned that many distances are ascertained and expressed in yards which it would be physically impossible to measure directly by a yard measure. In like manner the masses of bodies are frequently ascertained and expressed numerically which could not be placed in a balance and subjected to direct weighing.

24. **Density and Relative Density.**—If we consider any body or portion of matter, and if we conceive it to be divided into any number of parts having equal volumes, then, if the masses of these parts are equal, in whatever way the division be conceived as taking place, that body is one of *uniform density*. The *density* of such a body is the mass of the *unit of volume*. Consequently if M denote the mass, V the volume, and D the density of the body, we have

$$M = VD.$$

If now we have an equal volume V of any second substance whose mass is M′ and density D′, we shall have

$$M' = VD'.$$

Consequently $D : D' :: M : M'$; that is the densities of substances are in the same ratio as the masses of equal volumes of those substances. If now we take the density of distilled water at 4° C. to be unity, the relative density of any other substance is the ratio which the mass of any given volume of that substance at that temperature bears to the mass of an equal volume of water. Thus it is found that the mass of any volume of platinum is 22·069 times that of an equal volume of water, consequently the relative density of platinum is 22·069.

The relative density of a substance is generally called its *specific gravity*. Methods of determining it are given in Book III.

In French measures the *cubic decimètre* or *litre* of distilled water at 4° C. contains the unit of mass, the *kilogramme*; and therefore the mass in kilogrammes of V cubic decimètres of a substance whose specific gravity is D, will be given by the equation

$$M = VD.$$

The same equation will give the mass in *grammes* of the body, if V is given in cubic centimètres.

It has been ascertained that 27·7274 cubic inches of distilled water at the temperature 15°·5 C. or 60° F. contain a pound of matter. Consequently, if V is the *volume* of a body in cubic inches, D its *specific gravity*, its mass M in lbs. avoirdupois will be given by the equation

$$M = \frac{VD}{27{\cdot}7274}.$$

In this equation D is, properly speaking, the relative density of the substance at 60° F. when the density of water at 60° F. is taken as the unit.

25. **Velocity and its measure.**—When a material point moves, it describes a continuous line which may be either straight or curved, and is called its *path* and sometimes its *trajectory*. Motion which takes place along a straight line is called *rectilinear* motion; that which takes place along a curved line is called *curvilinear* motion. The rate of the motion of a point is called its *velocity*. Velocity may be either uniform or variable; it is *uniform* when the point describes equal spaces of portions of its path in all equal times; it is *variable* when the point describes unequal portions of its path in any equal times.

Uniform velocity is measured by the number of units of space described in a given unit of time. The units commonly employed are feet and seconds. If, for example, a velocity 5 is spoken of without qualification, this means a velocity of 5 feet per second. Consequently, if a body moves for t seconds with a uniform velocity v, it will describe vt feet.

The following are a few examples of different degrees of velocity expressed in this manner. A snail 0·005 feet in a second; military quick step 4·6; moderate wind 10; fast sailing vessel 18·0; channel steamer 22·0; railway train 36 to 75 feet; racehorse and storm 50 feet; eagle 100 feet; carrier pigeon 120 feet; a hurricane 160 feet; sound at 0° 1090;

a point on the equator in its rotation about the earth's axis 1520; a Martini-Henry rifle bullet 1330; a shot from an Armstrong gun 1180; the centre of the earth 101000; light and also electricity in a medium destitute of resistance 192000 miles.

Variable velocity is measured at any instant by the number of units of space a body would describe if it continued to move uniformly from that instant for a unit of time. Thus, suppose a body to run down an inclined plane, it is a matter of ordinary observation that it moves more and more quickly during its descent; suppose that at any point it has a velocity 15, this means that at that point it is moving at the rate of 15 ft. per second, or, in other words, if from that point all increase of velocity ceased, it would describe 15 ft. in the next second.

26. **Force.**—When a material point is at rest, it has no innate power of changing its state of rest; when it is in motion it has no innate power of changing its state of uniform motion in a straight line. This property of matter is termed its *inertia* (19). Any cause which sets a point in motion, or which changes the magnitude or direction of its velocity if in motion, is a *force*. *Gravity*, *friction*, *elasticity* of springs or gases, *electrical* or *magnetic attraction* or *repulsion*, etc. are *forces*. All changes observed in the motion of bodies can be referred to the action of one or more forces.

27. **Accelerative effect of force.**—If we suppose a force to continue unchanged in magnitude, and to act along the line of motion of a point, it will communicate in each successive second a constant increase of velocity. This constant increase is the *accelerative effect of the force*. Thus, if at any given instant the body has a velocity 10, and if at the end of the first, second, third, etc., second from that instant its velocity is 13, 16, 19, etc., the accelerative effect of the force is 3; a fact which is expressed by saying that the body has been acted on by an accelerating force 3.

If the force vary from instant to instant, its accelerative effect will also vary; when this is the case the accelerative effect at any instant is measured by the velocity it would communicate in a second if the force continued constant from that instant.

By means of an experiment to be described below (74) it can be shown that at any given place the accelerative effect of gravity g is constant; but it is found to have different values at different places; adopting the units of feet and seconds it is found that very approximately

$$g = f\,(1 - 0{\cdot}00256 \cos 2\phi)$$

at a station whose latitude is ϕ, where f denotes the number 32·1724.

28. **Momentum** or quantity of motion is a magnitude varying as the mass of a body and its velocity jointly, and therefore is expressed numerically by the product of the number of units of mass which it contains and the number of units of velocity in its motion. Thus a body containing 5 lbs. of matter, and moving at the rate of 12 ft. per second, has a momentum of 60.

29. **Measure of force.**—Force, when constant, is measured by the

momentum it communicates to a body in a unit of time. If the force varies, it is then measured at any instant by the momentum it would communicate if it continued constant for a unit of time from the instant under consideration. The *unit of force* is that force which acting on a pound of matter would produce in one second a velocity of one foot per second. Consequently, if a body contains m lbs. of matter, and is acted on by a force whose accelerative effect is f, that force contains a number of units of force (F), given by the equation

$$F = mf.$$

The weight of a body, *when that term denotes a force*, is the force exerted on it by gravity; consequently, if m is the mass of the body, and g the accelerating force of gravity, the number of units of force W exerted on it by gravity is given by the equation

$$W = mg$$

or (27) $$W = mf(1 - 0{\cdot}00256 \cos 2\phi).$$

From this it is plain that the weight of the same body will be different at different parts of the earth's surface; this could be verified by attaching a piece of platinum (or other metal) to a delicate spring, and noting the variations in the length of the spring during a voyage from a station in the Northern Hemisphere to another in the Southern Hemisphere, for instance, from London to the Cape of Good Hope.

When, therefore, a *pound* is used as a unit of force it must be understood to mean the force W exerted by gravity on a pound of matter in London. Now, in London, the numerical value of g is 32·1912, so that

$$W = 1 \times 32{\cdot}1912;$$ (see 51)

in other words, when a pound is taken as the unit of force it contains 32·1912 units of force according to the measure given above. It will be observed that a pound of matter is a completely determinate quantity of matter, irrespective of locality, but gravity exerts on a pound of matter a pound (or 32·1912 units) of force at London and other places in about the same latitude as London only; this ambiguity in the term *pound* should be carefully noticed by the student; the context in any treatise will always show in which sense the term is used.

30. **Representation of forces.**—Draw any straight line AB, and fix on any point O in it. We may suppose a force to act on the point O, along the line AB, either towards A or B: then O is called the *point of application* of the force, AB its line of action; if it acts towards A, its *direction* is OA, if towards B, its direction is OB. It is rarely necessary to make the distinction between the line of action and direction of a force; it being very convenient to make the convention that the statement—a force acts on a point O along the line OA—means that it acts from O to A. Let us suppose the force which acts on O along OA to contain P units of force; from O towards A measure ON containing P units of length, the line ON is said to *represent* the force. It will be remarked that the analogy between the line and the force is very

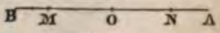

Fig. 3.

complete; the line ON is drawn from O in a given direction OA, and contains a given number of units P, just as the force acts on O in the direction OA, and contains a given number of units P. It is scarcely necessary to add, that if an equal force were to act on O in the opposite direction, it would be said to act in the direction OB, and would be represented by OM, equal in magnitude to ON.

When we are considering several forces acting along the same line we may indicate their directions by the positive and negative signs. Thus the forces mentioned above would be denoted by the symbols + P and − P respectively.

31. **Forces acting along the same line.**—If forces act on the point O in the direction OA equal to P and Q units respectively, they are equivalent to a single force R containing as many units as P and Q together, that is,

$$R = P + Q.$$

If the sign + in the above equation *denote algebraical* addition, the equation will continue true whether one or both of the forces act along OA or OB. It is plain that the same rule can be extended to any number of forces, and if several forces have the same line of action they are equivalent to one force containing the same number of units as their *algebraical* sum. Thus if forces of 3 and 4 units act on O in the direction OA, and a force of 8 in the direction OB, they are equivalent to a single force containing R units given by the equation

$$R = 3 + 4 - 8 = -1;$$

that is, R is a force containing one unit acting along OB. This force R is called their *resultant*. If the forces are in equilibrium R is equal to zero. In this case the forces have equal tendencies to move the point O in opposite directions.

32. **Resultant and components.**—In the last article we saw that a single force R could be found equivalent to several others; this is by no means peculiar to the case in which all the forces have the same line of action; in fact, when a material point, A (fig. 4), remains in equilibrium under the action of several forces, S, P, Q, it does so because any one of the forces, as S, is capable of neutralising the combined effects of all the others. If the force S, therefore, had its direction reversed, so as to act along AR, the prolongation of AS, it would produce the same effect as the system of forces P, Q.

Now, a force whose effect is equivalent to the combined effects of several other forces is called their *resultant*, and with respect to this resultant, the other forces are termed *components*.

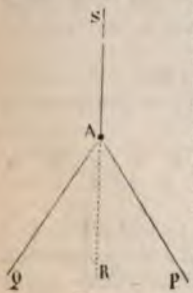

Fig. 4.

When the forces, P, Q, act on a point they can only have *one* resultant; but any single force can be resolved into components in an indefinite number of ways.

If a point move from rest under the action of any number of forces it will begin to move in the direction of their resultant.

33. **Parallelogram of forces.**—When two forces act on a point their resultant is found by the following theorem, known as the principle of the parallelogram of forces :—*If two forces act on a point, and if lines be drawn from that point representing the forces in magnitude and direction, and on these lines as sides a parallelogram be constructed, their resultant will be represented in magnitude and direction by that diagonal which passes through the point.* Thus let P and Q (fig. 5) be two forces acting on the point A along AP and AQ respectively, and let AB and AC be taken containing the same number of units of length that P and Q contain units of force ; let the parallelogram AB DC be completed, and the diagonal AD drawn ; then the theorem states that the resultant, R, of P and Q is represented by AD ; that is to say, P and Q together are equal to a single force R acting along the line AD, and containing as many units of force as AD contains units of length.

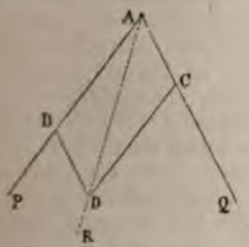

Fig. 5.

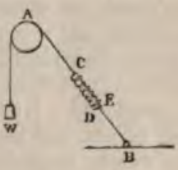

Fig. 6.

Proofs of this theorem are given in treatises on Mechanics ; we will here give an account of a direct experimental verification of its truth ; but before doing so we must premise an account of a very simple experiment. Let A (fig. 6) be a small pulley, and let it turn on a smooth, hard, and thin axle with little or no friction ; let W be a weight tied to the end of a fine thread which passes over the pulley ; let a spring CD be attached by one end to the end C of the thread and by the end D to another piece of thread, the other end of which is fastened to a fixed point B ; a scale CE can be fastened by one end to the point C and pass inside the spring so that the elongation of the spring can be measured. Now it will be found on trial that with a given weight W the elongation of the spring will be the same whatever the angle contained between the parts of the string WA and BA. Also it would be found that if the whole were suspended from a fixed point, instead of passing over the pulley, the weight would in this case stretch the spring to the same extent as before. This experiment shows that when care is taken to diminish to the utmost the friction of the axle of the pulley, and the imperfect flexibility of the thread, the weight of W is transmitted without sensible diminution to B, and exerts on that point a pull or force along the line BA virtually equal to W.

This being premised, an experimental proof, or illustration of the parallelogram of forces, may be made as follows :—

Suppose H and K (fig. 7) to be two pulleys with axles made as smooth and fine as possible; let P and Q be two weights suspended from fine and flexible threads which, after passing over H and K, are fastened at A to a third thread AL from which hangs a weight R; let the three weights come to rest in the positions shown in the figure. Now the point A is acted on by three forces in equilibrium, viz., P from A to H, Q from A to K, and R from A to L, consequently, any one of them must be equal and opposite to the resultant of the other two. Now if we suppose the apparatus to be arranged immediately in front of a large slate, we can draw lines upon it coinciding with AH, AK, and AL. If now we measure off along AH the part AB containing as many inches as P contains pounds, and along AK the part AC containing as many inches as Q contains pounds, and complete the parallelogram ABCD, it will be found that the diagonal AD is in the same line as AL, and contains as many inches as R weighs pounds. Consequently, the resultant of P and Q is represented by AD. Of course, any other units of length and force might have been employed. Now it will be found that when P, Q, and R are changed in any way whatever consistent with equilibrium, the same construction can be made,—the point A will have different positions in the different cases; but when equilibrium is established, and the parallelogram ABCD is constructed, it will be found that AD is vertical, and contains as many units of length as R contains units of force, and consequently it represents a force equal and opposite to R, that is, it represents the resultant of P and Q.

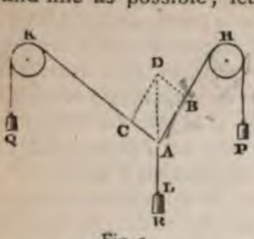

Fig. 7.

34. **Resultant of any number of forces acting in one plane on a point.**—Let the forces, P, Q, R, S (fig. 8) act on the point A, and let them be represented by the lines AB, AC, AD, AE, as shown in the figure. *First*, complete the parallelogram ABFC and join AF; this line represents the resultant of P and Q. *Secondly*, complete the parallelogram AFGD and join AG; this line represents the resultant of P, Q, R. *Thirdly*, complete the parallelogram AGHE and join AH; this line represents the resultant of P, Q, R, S. It is manifest that the construction can be extended to any number of forces. A little consideration will show that the line AH might be determined by the following construction :—through B draw BF parallel to, equal to, and towards the same part as AC; through F draw FG parallel to, equal to, and towards the same part as AD; through G draw GH parallel to, equal to, and towards the same part as AE; join AH, then AH represents the required resultant.

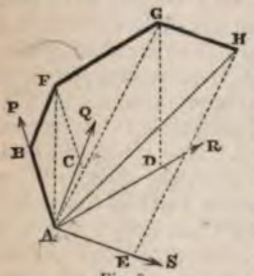

Fig. 8.

In place of the above construction, the resultant can be determined by calculation in the following manner:—Through A draw any two rectangular axes Ax and Ay (fig. 9), and let α, β, γ be the angles made with the axis Ax by the lines representing the pressures, then P, Q, R can be resolved into P cos α, Q cos β, R cos γ, acting along Ax, and P sin α, Q sin β, R sin γ, acting along Ay. Now the former set of forces can be reduced to a single force X by addition, attention being paid to the sign of each component; and in like manner the latter forces can be reduced to a single force Y, that is,

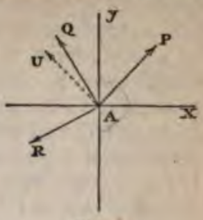

Fig. 9.

$$X = P\cos\alpha + Q\cos\beta + R\cos\gamma + \ldots$$
$$Y = P\sin\alpha + Q\sin\beta + R\sin\gamma + \ldots$$

Since the addition denotes the *algebraical* sum of the quantities on the right hand side of the equations, both *sign* and *magnitude* of X and Y are known. Suppose U to denote the required resultant, and ϕ the angle made by the line representing it with the axis Ax;

then $$U\cos\phi = X, \text{ and } U\sin\phi = Y.$$

These equations give $U^2 = X^2 + Y^2$, which determines the magnitude of the resultant, and then, since both sin ϕ and cos ϕ are known, ϕ is determined without ambiguity.

Thus let P, Q, and R be forces of 100, 150, and 120 units, respectively, and suppose xAP, xAQ, and xAR to be angles of 45°, 120°, and 210° respectively. Then their components along Ax are 70·7,—75,—103·9, and their components along Ay are 70·7,—129·9,—60. The sums of these two sets being respectively—108·2 and 140·6, we have $U\cos\phi = -108{\cdot}2$ and $U\sin\phi = 140{\cdot}6$.

therefore $$U^2 = (108{\cdot}2)^2 + (140{\cdot}6)^2$$

or $$U = 177{\cdot}4$$

therefore $$177{\cdot}4\cos\phi = -108{\cdot}2, \text{ and } 177{\cdot}4\sin\phi = 136{\cdot}7.$$

If we made use of the former of these equations only, we should obtain ϕ equal to 232° 25′, or 127° 35′, and the result would be ambiguous: in like manner, if we determined ϕ from the second equation only, we should have ϕ equal to 52° 25′, or 127° 35′; but as we have both equations, we know that ϕ equals 127° 35′, and consequently the force U is completely determined as indicated by the dotted line AU.

35. **Conditions of equilibrium of any forces acting in one plane on a point.**—If the resultant of the forces is zero, they have no joint tendency to move the point, and consequently are in equilibrium. This obvious principle enables us to deduce the following constructions and equations, which serve to ascertain whether given forces will keep a point at rest.

Suppose that in the case represented in fig. 8, T is the force which will balance P, Q, R, S. It is plain that T must act on A along HA produced, and in magnitude must be proportional to HA; for then the resultant of the five forces will equal zero, since the broken line ABFGHA returns to the point A. This construction is plainly equivalent to the following: Let P, Q, R (fig. 10) be forces acting on the point O, as indicated, their magnitudes and directions being given. It is known that they are balanced by a fourth force, S, and it is required to determine the magnitude and direction of S. Take any point D, and draw any line parallel to and towards the same part as OP, draw AB parallel to and towards the same parts as OQ, and take AB such that P : Q :: DA : AB. Through B draw BC parallel to and towards the same part as OR, taking BC such that Q : R :: AB : BC; join CD; through O draw OS parallel to and towards the same part as CD, then the required force S acts along OS, and is in magnitude proportional to CD.

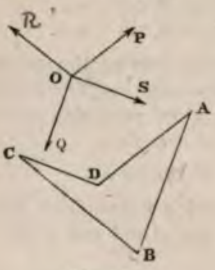

Fig. 10.

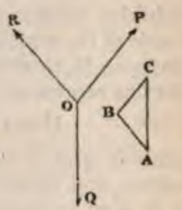

Fig. 11.

It is to be observed that this construction can be extended to any number of forces, and will apply to the case in which these directions are not in one plane, only in this case the broken line ABCD would not lie wholly in one plane. The above construction is frequently called the *Polygon of Forces.*

The case of three forces acting on a point is, of course, included in the above; but its importance is such that we may give a separate statement of it. Let P, Q, R (fig. 11) be three forces in equilibrium on the point O. From any point B draw BC parallel to and towards the same part OP, from C draw CA parallel to and towards the same part as OQ, and take CA such that P : Q :: BC : CA; then, on joining AB, the third force R must act along OR parallel to and towards the same part as AB, and must be proportional in magnitude to AB. This construction is frequently called the *Triangle of Forces.* It is evident that while the sides of the triangle are severally proportional to P, Q, R, the angles A, B, C are supplementary to QOR, ROP, POQ respectively, consequently every trigonometrical relation existing between the sides and angles of ABC will equally exist between the forces P, Q, R, and the supplements of the angles between their directions. Thus in the triangle ABC it is known that the sides are proportional to the sines of the opposite angles; now since the sines of the angles are equal to the sines of their supplements, we at once conclude that *when three forces are in equilibrium, each is proportional to the sine of the angle between the directions of the other two.*

We can easily obtain from the equations which determine the resultant of any number of forces (34), equations which express the conditions of equilibrium of any number of forces acting in one plane on a point: in fact, if $U=0$ we must have $X=0$ and $Y=0$; that is to say, the required conditions of equilibrium are these:—

$$0=P\cos\alpha+Q\cos\beta+R\cos\gamma+\ldots$$

and

$$0=P\sin\alpha+Q\sin\beta+R\sin\gamma+\ldots$$

The first of these equations shows that no part of the motion of the point can take place along Ax, the second that no part can take place along Ay. In other words, the point cannot move at all.

36. **Composition and resolution of parallel forces.**—The case of the equilibrium of three parallel forces is merely a particular case of the equilibrium of three forces acting on a point. In fact let P and Q be two forces whose directions pass through the points A and B, and intersect in O; let them be balanced by a third force R whose direction produced intersects the line AB in C. Now suppose the point O to move along AO, gradually receding from A, the magnitude and direction of R will continually change, and also the point C will continually change its position, but will always lie between A and B. In the limit P and Q become parallel forces, acting towards the same part balanced by a parallel force R acting towards the contrary part through a point X between A and B. The question is:—*First*, on this limiting case what is the value of R; *secondly*, what is the position of X? Now with regard to the first point it is plain, that if a triangle $a\,b\,c$ were drawn as in art. 35, the angles a and b in the limit will vanish, and c will become 180°, consequently $a\,b$ ultimately equals $a\,c+c\,b$;

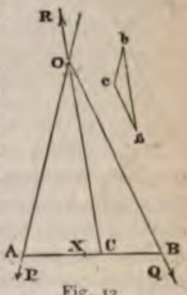

Fig. 12.

or

$$R=P+Q.$$

With regard to the second point it is plain that

$$OC\sin POR=OC\sin AOC=AC\sin CAO,$$

and

$$OC\sin ROQ=OC\sin BOC=CB\sin CBO;$$

therefore

$$AC\sin CAO : CB\sin CBO :: \sin POR : \sin ROQ$$
$$:: Q : P\ (35).$$

Now in the limit when OA and OB become parallel, OAB and OBA become supplementary; that is, their sines become equal; also AC and CB become respectively AX and XB; consequently

$$AX : XB :: Q : P,$$

a proportion which determines the position of X. This theorem at once leads to the rules for the composition of any two parallel forces, viz.

I. When two parallel forces P and Q act towards the same part, at rigidly connected points A and B, their resultant is a parallel force acting towards the same part, equal to their sum, and its direction divides the line AB into two parts AC and CB inversely proportional to the forces P and Q.

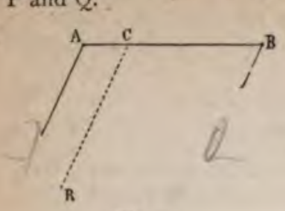

Fig. 13.

II. When two parallel forces P and Q act towards contrary parts, at rigidly connected points A and B of which P is the greater, their resultant is a parallel force acting towards the same part as P, equal to the excess of P over Q, and its direction divides BA produced in a point C such that CA and CB are inversely proportional to P and Q.

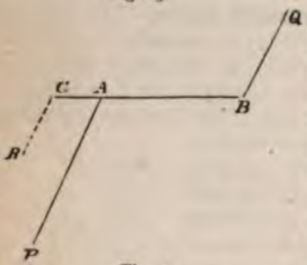

Fig. 14.

In each of the above cases if we were to apply R at the point C, in opposite direction to those shown in the figure, it would plainly (by the above theorem) balance P and Q, and therefore when it acts as shown in figs. 13 and 14 it is the resultant of P and Q in those cases respectively. It will of course follow that the force R acting at C can be resolved into P and Q acting at A and B respectively.

If the second of the above theorems be examined, it will be found that no force R exists equivalent to P and Q when those forces are equal. Two such forces constitute *a couple*, which may be defined to be two equal parallel forces acting towards contrary parts; they possess the remarkable property that they are incapable of being balanced by any single force whatsoever.

In the case of more than two parallel forces the resultant of any two can be found, then of that and a third, and so on to any number; it can be shown that however great the number of forces they will either be in equilibrium or reduce to a single resultant or to a couple.

37. **Centre of parallel forces.**—On referring to figs. 13 and 14, it will be remarked that if we conceive the points A and B to be fixed in the directions AP and BQ of the forces P and Q, and if we suppose those directions to be turned round A and B, so as to continue parallel and to make any given angles with their original directions, then the direction of their resultant will contiuue to pass through C; that point is therefore called *the centre* of the parallel forces P and Q.

It appears from investigation, that whenever a system of parallel forces reduces to a single resultant, those forces will have a centre; that is to say, if we conceive each of the forces to act at a fixed point, there will be a point through which the direction of their resultant will pass when the directions of the forces are turned through any equal angles round their points of application in such a manner as to retain the parallelism of their directions.

The most familiar example of a centre of parallel forces is the case in which the forces are the weights of the parts of a body; in this case the forces all acting towards the same part will have a resultant, viz. their sum; and their centre is called the *centre of gravity* of the body.

38. **Moments of forces.**—Let P denote any force acting from B to P, take A any point, let fall AN a perpendicular from A on BP. The product of the number of units of force in P, and the number of units of length in AN is called the moment of P with respect to A. Since the force P can be represented by a straight line, the moment of P can be represented by an area. In fact, if BC is the line representing P, the moment is properly represented by twice the area of the triangle ABC. The perpendicular AN is sometimes called the arm of the pressure. Now if a watch were placed with its face upward on the paper, the force P would cause the arm AN to turn round A in the *contrary* direction to the hands of the watch. Under these circumstances, it is usual to consider the moment of P with respect to the point A to be positive. If P acted from C to B, it would turn NA in the *same* direction as the hands of the watch, and now its moment is reckoned *negative*.

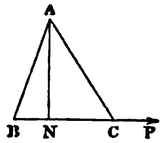

Fig. 15.

The following remarkable relation exists between any forces acting in one plane on a body and their resultant. Take the moments of the forces and of their resultant with respect to any one point in the plane. Then the moment of the resultant equals the sum of the moments of the several forces, regard being had to the *signs* of the moments.

If the point about which the moments are measured be taken in the direction of the resultant, its moment with respect to that point will be zero; and consequently the sum of the moments with respect to such point will be zero.

39. **Equality of Action and Reaction.**—We will proceed to exemplify some of the principles now laid down by investigating the conditions of equilibrium of bodies in a few simple cases; but before doing so we must notice a law which holds good whenever a mutual action is called into play between two bodies. *Reaction is always equal and contrary to action: that is to say, the mutual actions of two bodies on each other are always forces equal in amount and opposite in direction.* This law is perfectly general, and is equally true when the bodies are in motion as well as when they are at rest. A very instructive example of this law has already been given (33), in which the action on the spring, CD (fig. 6) is the weight W transmitted by the spring to C, and balanced by the reaction of the ground transmitted from B to D. Under these circumstances, the spring is said to be stretched by a force W. If the spring were removed, and the thread were continuous from A to B, it is clear that any part of it is stretched by two equal forces, viz. an action and reaction, each equal to W, and the thread is said to sustain a tension W. When a body is urged along a smooth surface, the mutual action can only take place along the common perpendicular at the point of contact. If, however, the bodies are rough, this restriction is partially removed, and now the mutual action can take place in any direction not making an angle greater than some determinate angle with the common perpendicular.

This determinate angle has different values for different substances, and is sometimes called the *limiting angle of resistance*, sometimes the *angle of repose*.

40. **The lever** is a name given to any bar straight or curved, AB, resting on a fixed point or edge *c* called the fulcrum. The forces acting on the lever are the *weight* or resistance Q, the *power* P, and the reaction of the fulcrum. Since these are in equilibrium, the resultant of P and Q must act through C, for otherwise they could not be balanced by the reaction. Draw *cb* at right angles to QB and *ca* to PA produced; then observing that P × *ca*, and Q × *cb* are the moments of P and Q with respect to *c*, and that they have contrary signs, we have by (38),

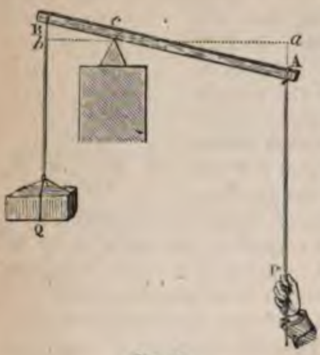

Fig. 16.

$$P \times ca = Q \times cb;$$

an equation commonly expressed by the rule, that *in the lever the power is to the weight in the inverse ratio of their arms.*

Levers are divided into three kinds, according to the position of the fulcrum with respect to the points of application of the power and the weight. In a *lever of the first kind* the fulcrum is between the power and i/ resistance, as in fig. 16. In a *lever of the second kind* the resistance is between the power and the fulcrum, as in a wheelbarrow or a pair of nutcrackers; in a *lever of the third kind* the power is between the fulcrum and the resistance, as in a pair of tongs or the treadle of a lathe.

41. **The single pulley.**—In the case of the single fixed pulley, shown in fig. 17, it follows at once from (33) that when the forces P and Q are in equilibrium they will be equal, the axle of the pulley being supposed perfectly smooth and the thread perfectly flexible. The same conclusion follows directly from the principle of moments; for the resultant of P and Q must pass through C, or otherwise they would cause the pulley to turn; now their moments are respectively P × CM and Q × CN, and since these have opposite signs we have (38)

$$P \times CM = Q \times CN.$$

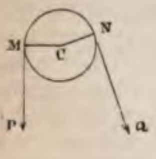

Fig. 17.

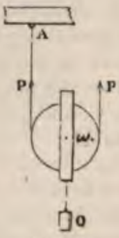

Fig. 18.

But CM and CN being equal, this equation shows that P and Q are equal. In the case of the single moveable pulley, shown in fig. 18, we have one end of the rope fastened to a point A in a beam. The pulley is consequently supported by two forces, viz. P and the reaction of the fixed point which is equal to P; these two forces support Q and the

the pulley *w*. In the case represented in the figure the parts e are parallel, consequently (36)

$$2P = Q + w.$$

veral pulleys are united into one machine, they constitute a pulleys; such are—the Block and Tackle, the Barton, White's tc.

e inclined plane.—A very instructive and useful application of ution of forces is to be found in the case of a body supported on ed plane. Let AB (fig. 19) be the plane, AC its base, and BC its let a body M considered as a point, ass is M and weight M*g* or Q, be sup- it by a force P acting along MB. The supposed to be smooth, and therefore M with a force R at right angles to AB. at right angles to AB, then the point at rest by forces P, Q, R, whose direc- severally parallel to the sides of the triangle DBC which is CBA. Hence

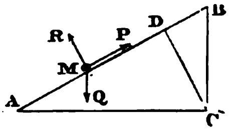

Fig. 19.

$$P : R : Q :: BD : DC : CB :: BC : CA : AB;$$

$$BC = AB \sin A \text{ and } CA = AB \cos A,$$

$$P = Q \sin A \text{ and } R = Q \cos A.$$

me fact may be stated in this form :—When a mass M is placed lined plane, its pressure on the plane is M*g* cos A and its force plane is M*g* sin A. In the above case these forces are balanced R respectively.

uppose BC and CA to be 9 ft. and 12 ft., respectively, then AB 15 ft. Consequently, if the weight of Q is 360 lbs. it produces lane a perpendicular pressure of 288 lbs., and requires for its force of 216 lbs. acting up the plane.

e wedge.—This instrument is nothing but a moveable inclined t is used in several forms, of which the annexed is, perhaps, the howing the action of the forces called into play. AB is a fixed CDE is a piece which is prevented from moving in a lateral by a fixed guide F. ABC is a wedge whose angle is such that faces is in contact with a face of ACDE as shown in the figure. ng forced forward by P, overcomes the resistance Q acting on The various forces called into play are ed in the diagram, namely, P, Q, the re- the table S, the mutual action between s R, R_1 and the reaction T of the guide will suppose the angles B, D, E, and be right angles, and that P and Q act angles to DE and BC respectively. , since the surfaces in contact are acts in a direction at right angles to d R_1 to AC, and T to AE. Through G at right angles to AC; *then the body ABC* being kept in

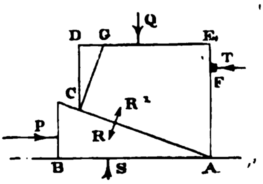

Fig. 20.

equilibrium by three forces, P, R, S, whose directions are respectively parallel to the sides of the triangle DGC, we have

$$P : R :: DG : GC.$$

The body ACDE being kept in equilibrium by three forces, T, R_1, Q, whose directions are respectively parallel to the side of the triangle DGC, we have

$$R_1 : Q :: GC : CD.$$

Now R and R_1 are equal, being the mutual actions of the two bodies, ABC, ACDE; therefore compounding the ratios, we have

$$P : Q :: DG : DC;$$

or, by similar triangles,

$$P : Q :: CB : BA,$$

a proportion equivalent to the equation

$$P = Q \tan A.$$

44. **The screw.**—It will be remarked that when the wedge is used as in the last article, Q cannot be many times greater than P, and also that the space through which P can lift Q is limited. The screw is merely a modification of the wedge by which the limits of its application in both these respects are extended. To explain this, it may be observed that if the thread of a screw were reduced to a line, it would become a curve called the *helix*, running in whorls round the cylinder; the distance between any two consecutive turns measured parallel to the axis of the cylinder being constant, and called the *pitch* of the screw. Now if ABC (fig. 20) were wrapped round a cylinder, whose dimensions were such that the base AB coincided with the circumference of the base of the cylinder, and the height BC with the pitch, the hypothenuse CA could be brought into coincidence with one whorl of the helix. Under these circumstances, the angle BAC (A) is called the *inclination of the thread*, and if r denote the radius of the base of the cylinder, h the pitch of the screw, we shall have, since AB tan A equals BC (fig. 20),

$$2\pi r \tan A = h.$$

Moreover, if ACDE were wrapped round the inside of a hollow cylinder or *nut* (fig. 21) of equal radius it would take the form of a helix, or companion screw cut on the inside of the nut; and if the screw were placed within the nut the two helices would be in exact contact. If now we suppose the power to act at the end of an arm, we shall have transformed the wedge of fig. 20 into a screw, one end of which works on a fixed table with a moveable nut. The annexed figure shows the arrangement, half the nut being removed in order to show how the thread of the screw works within the groove of the companion. When the arm is turned in the direction indicated by P the point B will pass to B′, but as the nut is kept by the guides G, H from turning with the screw, it must now occupy the point C of the companion, and consequently the nut must be lifted so that C comes to B′. If the nut were fixed the screw would be depressed by the same amount, when P acts as indicated.

he screw were turned by a force P′ acting tangentially to the base cylinder, it is plain that when all frictions are neglected the relation n P′ and Q must be the same t between P and Q in the last , that is,

$$P' = Q \tan A$$

$$2\pi r\, P' = Qh\,;$$

acting perpendicularly at the an arm *a* will have (by equality ments) the same tendency as P′ n the screw, provided

$$P'r = Pa,$$

erefore the relation between P is given by the equation

$$2\pi a\, P = Qh\,;$$

power has to the resistance me ratio which the pitch of the has to the circumference of the described by the end of the arm ; ample, if *h* equal 1 inch, and *a* 2 ft., a power of 100 lbs. would me a resistance not exceeding lbs.

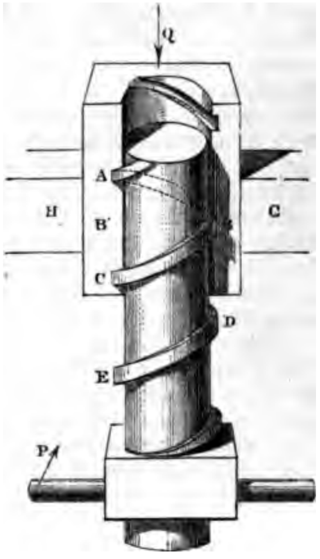

Fig. 21.

riction.—In the cases of the actions of machines which have escribed, the resistances which are offered to motion have not been considered. The surfaces of bodies in contact are never perfectly h ; even the smoothest present inequalities which can neither be ed by the touch nor by ordinary sight ; hence when one body moves he surface of another the elevations of one sink into the depressions other, like the teeth of wheels, and thus offer a certain resistance to : this is what is called *friction.* It must be regarded as a force continually acts in opposition to actual or possible motion.

tion is of two kinds : *sliding,* as when one body glides over another ; east when the two surfaces in contact remain the same as in the of an axle in its bearing ; and *rolling* friction, which occurs when dy rolls over another, as in the case of an ordinary wheel. The is less than the former, for by the rolling the inequalities of one body sed over another.

force which is required to overcome friction and which is briefly of as friction is proportional to the pressure of the two bodies each other. That fraction of the pressure which is required to me friction is called the *coefficient of friction.*

tion is independent of the extent of surfaces in contact, it is diminished by polishing and by smearing, but is increased by heat. It is as a body passes from the *state of rest to that* of motion than during motion, but seems independent of the velocity. The coefficient of friction depends on the nature of the substances in contact; thus, for oak upon oak it is 0·418 when the fibres are parallel and 0·293 when they cross, for beech upon beech it is 0·36. Greasy substances which are not absorbed by the body diminish friction; but increase it if they are absorbed. Thus moisture and oil increase, while tallow, soap, and graphite diminish, the friction of wooden surfaces. In the sliding friction of cast iron upon bronze the coefficient was found to be 0·25 without grease; with oil it was 0·17, fat 0·11, soap 0·03, and with a mixture of fat and graphite 0·02. The coefficient of rolling friction for cast iron wheels on iron rails is 0·004; for ordinary wheels on an ordinary road it is 0·04.

As rolling friction is considerably less than sliding friction, it is a great saving of power to convert the latter into the former as is done in the case of the castors of chairs and other furniture. On the other hand, it is sometimes useful to change rolling into sliding friction, as when drags are placed on carriage wheels.

Without friction on the ground, neither men nor animals, neither ordinary carriages nor railway carriages could move. Friction is necessary for the transmission of power from one wheel to another by means of bands or ropes; and without friction we could hold nothing in the hands.

46. **Uniformly accelerated rectilinear motion.**—Let us suppose a body containing m units of mass to move from rest under the action of a force, of F units, the body will move in the line of action of the force, and will acquire in each second an additional velocity f given by the equation

$$F = mf$$

consequently, if v is its velocity at the end of t seconds, we have

$$v = ft. \qquad (1)$$

To determine the space it will describe in t seconds, we may reason as follows:—The velocity at the time t being ft, that at a time $t+\tau$ will be $f(t+\tau)$. If the body moved uniformly during the time τ with the former velocity it would describe a space s equal to $ft\tau$, if with the latter velocity a space s_1 equal to $f(t+\tau)\tau$. Consequently,

$$s_1 : s :: t+\tau : t$$

therefore, when τ is indefinitely small, the limiting values of s and s_1 are equal. Now since the body's velocity is continually *increasing* during the time τ the space actually described is greater than s, and less than s_1. But since the limiting values of s and s_1 are equal, the limiting value of the space described is the same as that of s or s_1. In other words, if we suppose the whole time of the body's motion to be divided into any number of equal parts, if we determine the velocity of the body at the beginning of each of these parts, and if we ascertain

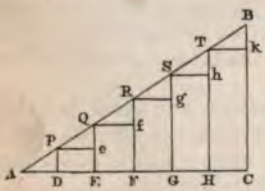

Fig. 22.

s described on the supposition that the body moves uniformly
ıch portion of time, the limiting value of the sum of these
ill be the space actually described by the body. Draw a
and at A construct an angle CAB, whose tangent equals f;
C into any number of equal parts in D, E, F,...and draw
, RF,...BC at right angles to AC, then since PD = AD × f,
× f, RF = AF × f, BC = AC × f, etc., PD will represent the velocity
dy at the end of the time represented by AD, and similarly QE,
, will represent the velocity at the end of the times AE.AF,...
mplete the rectangles De, Ef, Fg... These rectangles represent
described by the body on the above supposition during the
hird, fourth,...portions of the time. Consequently, the space
described during the time AC is the limit of the sum of the
s; the limit being continually approached as the number of parts
h AC is divided is continually increased. But this limit is the
ıe triangle ABC : that is $\frac{1}{2}$AC × CB or $\frac{1}{2}$AC × AC × f. Therefore,
›resents the time t during which the body describes a space s,

$$s = \tfrac{1}{2}ft^2. \qquad (2)$$

s equation can be written

$$2fs = f^2t^2$$

›n comparing this with equation (1), that

$$v^2 = 2fs. \qquad (3)$$

ate these equations, let us suppose the accelerative effect of the
ıe 6, that is to say, that in virtue of the action of the force, the
uires in each successive second an additional velocity of 6 ft. per
nd let it be asked what, on the supposition of the body moving
, will be the velocity acquired and the space described at the
seconds; equations 1 and 2 enable us to answer that at that
will be moving at the rate of 72 ft. per second and will have
432 ft.

lowing important result follows from equation 2. At the *end*
t, second, third, fourth, etc. second of the motion the body will
scribed $\frac{1}{2}f$, $\frac{1}{2}f \times 4$, $\frac{1}{2}f \times 9$, $\frac{1}{2}f \times 16$, etc., ft., and consequently
e first, second, third, fourth, etc. second of the motion will have
$\frac{1}{2}f$, $\frac{1}{2}f \times 3$, $\frac{1}{2}f \times 5$, $\frac{1}{2}f \times 7$, etc. ft., namely, spaces in arithmetical
ɔn.

sults of the above article can be stated in the form of laws
ɔly to the state of a body moving from a state of rest :—

velocities are proportional to the times during which the motion

spaces described are proportional to the squares of the times
in their description.

e spaces described are proportional to the squares of the velocities
uring their description.

spaces described in equal successive periods of time increase by
quantity.

Instead of supposing the body to begin to move from a state of rest, we may suppose it to have an initial velocity V, in the direction of the force. In this case equations 1, 2, and 3 can be easily shown to take the following forms respectively :—

$$v = V + ft$$
$$s = Vt + \tfrac{1}{2}ft^2$$
$$v^2 = V^2 + 2fs.$$

If the body move in a direction opposite to that of the force, f must be reckoned negative.

The laws stated in the present article apply directly to the case of a body falling freely *in vacuo.* In this case the force causing the acceleration is that of gravity, and it is usual to denote the acceleration produced, by the letter g; it has already been stated (27 and 29) that the numerical value of g, is 32·1912 at London, when the unit of time is a second and the unit of a distance a foot.

47. **Motion on an inclined plane.**—Referring to (42), suppose the force P not to act; then the mass M is acted on by an unbalanced force Mg sin A, in the direction MA, consequently the accelerating force down the plane is g sin A, and the motion becomes a particular case of that discussed in the last article. If it begin to move from rest, it will at the end of t seconds acquire a velocity v given by the equation

$$v = gt \sin A,$$

and will describe a length s (ft.) of the plane given by the equation

$$s = \tfrac{1}{2}gt^2 \sin A.$$

Also, if v is the velocity acquired while describing s feet of the plane

$$v^2 = 2gs \sin A.$$

Hence (fig. 19) if a body slides down the plane from B to A the velocity which it acquires at A equals $\sqrt{2g.\mathrm{AB} \sin A}$ or $\sqrt{2g.\ \mathrm{BC}}$. that is to say, the velocity which the body has at A does not depend on the angle A, but only on the perpendicular height BC. The same would be true if for BA we substituted any smooth curve, and hence we may state generally, that when a body moves along any smooth line under the action of gravity, the change of velocity it experiences in moving from one point to another is that due to the *vertical* height of the former point above the latter.

48. **Composition of velocities.**—The rule for the composition of velocities is the same as that for the composition of forces ; this follows evidently from the fact that forces are measured by the momentum they communicate, and are therefore to one another in the same ratio as the velocities they communicate to the *same* body. Thus (fig. 5, art. 33) if the point has at any instant a velocity AB, in the direction AP, and there is communicated to it a velocity AC in the direction AQ, it will move in the direction AR with a velocity represented by AD. And conversely, the velocity of a body represented by AD can be resolved into

two component velocities AB and AC. This suggests the method of determining the motion of a body when acted on by a force in a direction transverse to the direction of its velocity; namely, suppose the time to be divided into a great number of intervals, and suppose the velocity actually communicated by the force to be communicated at once, then by the composition of velocities we can determine the motion during each interval, and therefore during the whole time; the actual motion is the limit to which the motion, thus determined, approaches when the number of intervals is increased.

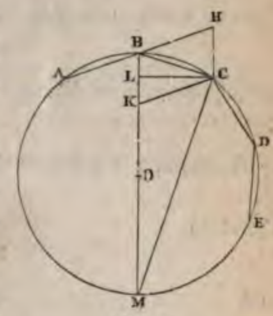

Fig. 23.

49. **Motion in a circle.**—Let ABCD...be a regular polygon inscribed in a circle whose centre is O. Draw the diameter BOM. Produce AB to H, making BH equal to AB, join CH, this line is parallel to BO. Draw CK parallel to BH; and CL at right angles at BO. Join CM. Suppose a body whose mass is M to describe AB with a velocity V in a time *t*, suppose that at B there is suddenly communicated to it in the direction BO, a velocity *ft* which is the same velocity as a force M*f* would communicate gradually in the same time *t*, it will move during the next short time *t*, with the velocity compounded of V and *ft*; now since BH equals V*t*, if *f* is such that BK equals $ft \times t$, the body will describe BC, in the second interval. It will be observed that as BC and AB are equal and are described in equal times *t*, the velocity along BC is the same as along AB, that is, the effect of the composition is to change the direction, not the amount of the velocity. When the body is at the point C we may suppose a velocity *ft* to be communicated in the direction CO, and then at the end of the third interval the body will be at D. On this supposition therefore the body will describe the polygon, ABCD...with a uniform velocity V. Now from similar triangles MCB, BCL we have

$$MB : BC :: BC : BL$$

or

$$2r : Vt :: Vt : \tfrac{1}{2}(ft) \times t$$

where r denotes the radius of the circle;

therefore

$$fr = V^2.$$

This is true for all values of *t*, and therefore also when *t* is indefinitely small. Now by diminishing *t* we merely increase the number of sides of the polygon, therefore when *t* is indefinitely small, the motion takes place in the circle, and the force M*f* acts continuously towards the centre.

This is a most important mechanical truth, it may therefore be well to illustrate as well as prove it. Suppose a mass containing 6 lbs. of matter to describe a circle whose radius is 5 ft. with an uniform velocity of 20 ft. per second. The force acting on it tending to the centre will contain $6 \times 20^2 \div 5$ or 480 units of force. In virtue of its inertia the body tends at each point to move along the tangent at that point, consequently a force must continually act on it *towards* the centre to deflect it from the tangent, and keep it moving in the circle ; in the above case the force contains 480 units, which is nearly 15 lbs. of force.

50. **Motion in a vertical circle.**—Let ACDB be a circle whose plane is vertical and radius denoted by r. Suppose a point placed at A, and allowed to slide down the curve, what velocity will it have acquired on reaching any given point P ? Draw the vertical diameter CD, join CA, CP, and draw the horizontal lines AMB and PNP′. Now assuming the curve to be smooth the velocity acquired in falling from A to P is that due to MN the vertical height of A above P (47) ; if, therefore, v denote the velocity of the point at P, we shall have

$$v^2 = 2g\,\mathrm{MN}.$$

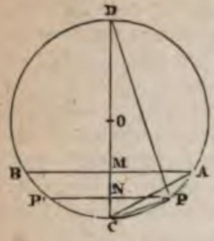

Fig. 24.

Now by similar triangles DCP, PCN we have

$$\mathrm{DC} : \mathrm{CP} :: \mathrm{CP} : \mathrm{CN}$$

consequently, if we denote by s the chord CP,

$$2r\,\mathrm{NC} = s^2$$

in like manner if a denote the chord CA,

$$2r\,\mathrm{MC} = a^2$$

therefore

$$2r\,\mathrm{MN} = a^2 - s^2$$

and

$$v^2 = \frac{g}{r}(a^2 - s^2).$$

It will be remarked that v will have equal values when s has the same value whether positive or negative, and for any one value of s there are two equal values of v, one positive and one negative. That is to say, since CP′ is equal to CP, the body will have the same velocity at P′ that it has at P, and at any point the body will have the same velocity whether it is going up the curve or down the curve. Of course it is included in this statement, that if the body begins to move from A it will just ascend to a point B on the other side of C, such that A and B are in the same horizontal line. It will also be remarked that at C the value of s is zero ; consequently, if V is the velocity acquired by the body in falling from A to C we have

$$\mathrm{V} = a\sqrt{\frac{g}{r}};$$

and, on the other hand, if the body begins to move from C with a velocity V it will reach a point A such that the chord AC or a is given by the same equation. In other words, the velocity at the lowest point is proportional to the chord of the arc described.

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51. **Motion of a simple pendulum.**—By a simple pendulum is meant a heavy particle suspended by a fine thread from a fixed point, about which it oscillates without friction. So far as its changes of velocity are concerned they will be the same as those of the point in the previous article, for the tension of the thread acting at each position in a direction at right angles to that of the motion of the point, will no more affect its motion than the reaction of the smooth curve affects that of the point in the last article. The time of an oscillation, that is, the time in which the point moves from A to B, can be easily ascertained when the arc of vibration is small, that is, when the chord and the arc do not sensibly differ.

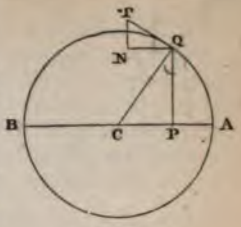

Fig. 25.

Thus, let AB (fig. 25) equal the arc or chord ACB (fig. 24), with centre C and radius AC or a describe a circle, and suppose a point to describe the circumference of that circle with a uniform velocity V or $a\sqrt{\frac{g}{r}}$. At any instant let the point be at Q, join CQ, draw the tangent QT, also draw QP at right angles and QN parallel to AB, then the angles NQT and CQP are equal. Now the velocity of Q resolved parallel to AB is V cos TQN or $a\sqrt{\frac{g}{r}}$ cos CQP, that is, if CP equals s, the velocity of Q parallel to AB is

$$\sqrt{\frac{g}{r}}\,\text{PQ} \text{ or } \sqrt{\frac{g}{r}(a^2-s^2)}.$$

But if we suppose a point to move along AB in such a manner that its velocity in each position is the same as that of the oscillating body, its velocity at P would also equal $\sqrt{\frac{g}{r}(a^2-s^2)}$; and, therefore, this point would describe AB in the same time that Q describes the semicircumference ACB. If then t be the required time of an oscillation we have

$$t=\pi a \div a\sqrt{\frac{g}{r}}=\pi\sqrt{\frac{r}{g}}.$$

This result is independent of the length of the arc of vibration, provided its *amplitude*, that is AB, be small. It is evident from the formula that the time of a vibration is directly proportional to the square root of the length of the pendulum, and inversely proportional to the square root of the accelerating force of gravity.

As an example of the use of the formula we may take the following:—It has been found by careful experiment that 39·13983 inches is the length of a simple pendulum, whose time of oscillation at Greenwich is one second; the formula at once leads to an accurate determination of the accelerating force of gravity g; for using feet and seconds as our units we have $t=1$, $r=3{\cdot}26165$, and π stands for the known number 3·14159, therefore the formula gives us

$$g=(3{\cdot}14159)^2\times 3{\cdot}26165=32{\cdot}1912.$$

This is the value employed in (29).

52. **Graphic representation of the changes of velocity of an oscillating body.**—The changes which the velocity of a vibrating body undergoes may be graphically represented as follows :—Draw a line of indefinite length and mark off AH to represent the time of one vibration. HH′ to represent the time of the second vibration, and so on. During the first vibration the velocity increases from zero to a maximum at the half vibration, and then decreases during the second half vibration from the maximum to zero. Consequently, if a curved line or arc AQH is drawn, the ordinate QM at any point Q will represent the velocity of the body at the time represented by AM. If a similar curved line or arc HPH′ be drawn, the ordinate PN of any point P will represent the velocity at a time denoted by AN. But since the *direction* of the velocity in the second oscillation is contrary to that of the velocity in the first oscillation, the ordinance NP must be drawn in the contrary direction to that of MQ. If, then, the curve be continued by a succession of equal arcs alternately on opposite sides of AD, the variations of the velocity of the vibrating body will be completely represented by the varying magnitudes of the ordinates of successive points of the curve.

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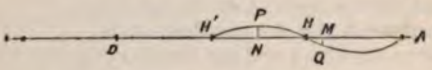


Fig. 26.

53. **Conical pendulum.**—When a point P is suspended from a point A as a simple pendulum, it can be caused to describe a horizontal circle with a uniform velocity V. A point moving in such a manner constitutes what is called a *conical pendulum*, and admits of many useful and interesting applications. We will, in this place, ascertain the relation which exists between the length r of the thread, AP, the angle of the cone PAN or θ, and the velocity V. Since the point P moves in a circle, whose radius is PN with a velocity V, a force R must act on it in the direction PN given by the equation (49)

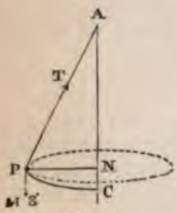


Fig. 27.

$$R=M\frac{V^2}{PN}.$$

Now the only forces acting are the tension of the thread T along PA, and the weight of the body Mg vertically, consequently their resultant must be a force R acting along PN. And therefore these forces will be parallel to the sides of the triangle ANP. So that (35)

$$R=Mg\frac{PN}{AN},$$

therefore

$$M\frac{V^2}{PN} = Mg\frac{PN}{AN},$$

or

$$V^2 = g\frac{PN^2}{AN}.$$

Now

$$PN = r\sin\theta \text{ and } \frac{PN}{AN} = \tan\theta,$$

therefore

$$V^2 = gr\sin\theta\tan\theta.$$

One conclusion from this may be noticed. With centre A and radius AP, describe the arc PC. Now when the angle PAC is small, the sine, PN, does not sensibly differ from the chord, nor the cosine, AN, from the radius, therefore in this case we have

$$V^2 = g\,.\,\frac{(\text{chd PC})^2}{\text{radius}} \text{ or } V = \text{chd PC}\sqrt{\frac{g}{r}}.$$

On comparing this result with (50) we see that when the angle PAN is small, the velocity of P moving in a conical pendulum is the same as P would have at the lowest point C if it oscillated as a simple pendulum; consequently, if we conceive the point P to be making small oscillations about the point A, and denote the velocity at the lowest point bv V, and if when at the extreme point of the arc of vibration, there is communicated to it a velocity V in a direction at right angles to the plane of vibration, its motion will be changed into that of a conical pendulum.

54. **Impulsive forces.**—When a force acts on a body for an inappreciably short time, and yet sensibly changes its velocity, it is termed an *instantaneous* or *impulsive* force. Such a force is called into play when one body strikes against another. A force of this character is nothing but a finite though very large force, acting for a time so short that its duration is nearly, or quite, insensible. In fact, if M is the mass of the body, and the force contains Mf units, it will, in a time t, communicate a velocity ft; now, however small t may be, Mf and therefore f may be so large that ft may be of sensible or even considerable magnitude. Thus if M contain a pound of matter, and if the force contain ten thousand units, though t were so short as to be only the $\frac{1}{1000}$th of a second, the velocity communicated by the force would be one of 10 ft. per second. It is also to be remarked that the body will not sensibly move while this velocity is being communicated; thus, in the case supposed, the body would only move through $\frac{1}{2}ft^2$ or the $\frac{1}{200}$th of a foot while the force acts upon it.

When one body impinges on another it follows from the law of the equality of action and reaction (39) that whatever force the first body exerts upon the second, the second will exert an equal force upon the first in the opposite direction; now forces are proportional to the momenta generated in the same time; consequently, these forces generate, during the whole or any part of the time of impact, in the bodies respectively, equal momenta with contrary signs; and therefore the sum of the momenta of the two bodies will remain constant during and at the end of the impact. It is of course understood that if the two bodies move in contrary directions their momenta have opposite signs and the sum is an algebraical sum. In order to test the physical validity of this conclusion, Newton made a series of experiments, which may be briefly described thus :—two balls A and B are hung from points C, D, in the same horizontal line by threads in such a manner that their centres A and B are in the same horizontal line. With centre C and radius CA describe a semicircle EAF, and with centre D and radius DB describe a semicircle GBH on the wall in front of which the balls hang. Let A be moved back to R, and be allowed to descend to A; it there impinges on B, both A and B will now move, along the arcs AF and BH respectively; let A and B come to their highest points at r and k respectively. Now if V denote the velocity with which A reaches the lowest point, v and u the velocities with which A and B leave the lowest points after impact, and r the radius AC, it appears from (50) that

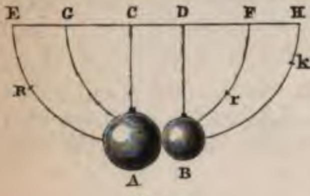


Fig. 28.

$$V = \text{chd AR}\sqrt{\frac{g}{r}},\ v = \text{chd A}r\sqrt{\frac{g}{r}},\ \text{and } u = \text{chd B}k\sqrt{\frac{g}{r}};$$

therefore if A and B are the masses of the two balls, the momentum at the instant before impact was A × chd AR and the momentum after impact was A × chd Ar + B × chd Bk. Now when the positions of the points R, r, and k had been properly corrected for the resistance of the air, it was found that these two expressions were equal to within quantities so small that they could be properly referred to errors of observation. The experiment succeeded equally under every modification, whether A impinged on B at rest or in motion, and whatever the materials of A and B might be.

55. **Direct collision of two bodies.**—Let A and B be two bodies moving with velocities V and U respectively, along the same line, and let their mutual action take place in that line; if the one overtake the other, what will be their respective velocities at the instant after impact? We will answer this question in two extreme cases.

i. Let us suppose the bodies to be *quite inelastic*. In this case, when A touches B, it will continue to press against B until their velocities are equalised, when the mutual action ceases. For whatever deformation the bodies may have undergone, they have no tendency to recover their shapes. If, therefore, x is their common velocity after impact, we shall have Ax + Bx their joint momentum at the end of impact, but their momentum before impact was AV + BU. Whence

$$(A + B)\,x = AV + BU,$$

an equation which determines x.

ii. Let us suppose the bodies *perfectly elastic*. In this case they recover their shapes, with a force exactly equal to that with which they were compressed. Consequently, the whole momentum lost by the one, and gained by the other, must be exactly double of that lost while compression took place, that is up to the instant at which their velocities were equalised. But these are respectively $AV - Ax$ and $Bx - BU$; therefore, if v and u are the required final velocities,

$$Av = AV - 2(AV - Ax) \text{ or } v = -V + 2x$$

$$Bu = BU + 2(Bx - BU) \text{ or } u = 2x - U$$

hence

$$(A + B)\ v = 2BU + (A - B)V$$

and

$$(A + B)\ u = 2AV - (A - B)U.$$

The following conclusion from these equations may be noticed: suppose a ball A, moving with a velocity V, to strike directly an equal ball B at rest. In this case $A = B$, and $U = 0$, consequently $v = 0$ and $u = V$, that is, the former ball A is brought to rest, and the latter B moves on with a velocity V. If now B strike on a third equal ball C at rest, B will in turn be brought to rest, and C will acquire the velocity V And the same is true if there is a fourth, or fifth, or indeed any number of balls. This result may be shown with ivory balls, and if carefully performed is a very remarkable experiment.

56. **Work: meaning of the term.**—It has been pointed out (19, 26) that a moving body has no power of itself to change either the direction or the speed of its motion, and that, if any such change takes place, it is a proof that the body is acted upon by some external force. But although change of motion thus always implies the action of force, forces are often exerted without causing any change in the motion of the bodies on which they act. For instance, when a ship is sailing at a uniform speed the force exerted on it by the wind causes no change in its motion, but simply prevents such a change being produced by the resistance of the water; or, when a railway-train is running with uniform velocity, the force of the engine does not change, but only maintains its motion in opposition to the forces, such as friction and the resistance of the air, which tend to destroy it.

These two classes of cases, namely, first, those in which forces cause a change of motion; and secondly, those in which they prevent, wholly or in part, such a change being produced by other forces, include all the effects to which the action of forces can give rise. When acting in either of these ways, a force is said to *do work*: an expression which is used scientifically in a sense somewhat more precise, but closely accordant with that in which it is used in common language. A little reflection will make it evident that, in all cases in which we are accustomed to speak of work being done,—whether by men, horse-power or steam power, and however various the products may be in different cases,—the physical part of the process consists solely in producing or changing motion, or in keeping up motion in opposition to resistance, or in a combination of these actions. The reader will easily convince himself of this by calling to mind what the definite actions are which constitute the work done by (say) a navvy, a joiner, a mechanic, a weaver; that done by a horse, whether employed in drawing a vehicle or in turning a gin; or that of a steam-engine, whether it be used to drag a railway-train or to drive machinery. In all cases the work done is reducible, from a mechanical point of view, to the elements that have been mentioned, although it may be performed on different materials, with different tools, and with different degrees of skill.

It is, moreover, easy to see (comp. 48, 49) that any possible change of motion may be represented as a gain by the moving body of an additional (positive or negative) velocity either in the direction of its previous motion, or at right angles to it; but a body which gains velocity is (27) said to be *accelerated*. Hence, what has been said above may be summed up as follows:—*When a force produces acceleration, or when it maintains motion unchanged in opposition to resistance, it is said to do* WORK.

57. **Measure of Work.**—In considering how work is to be measured, or how the relation between different quantities of work is to be expressed numerically, we have, in accordance with the above, to consider first, *work of acceleration*; and secondly, *work against resistance*. But in order to make the evaluation of the two kinds of work consistent, we must bear in mind that one and the same exertion of force will result in work of either kind, according to the conditions under which it takes place: thus, the force of gravity acting on a weight let fall from the hand causes it to move with a continually accelerated velocity until it strikes the ground; but if the same weight, instead of being allowed to fall freely through the air, be hung to a cord passing round a cylinder by means of which various degrees of friction can be applied to hinder its descent, it can be made to fall with a very small and practically uniform velocity. Hence, speaking broadly, it may be said that, in the former case, the work done by gravity upon the weight is work of acceleration only, while in the latter case it is work against resistance (friction) only. But it is very important to note that an essential condition, without which a force, however great, cannot do work either of one kind or the other, is that the thing acted on by it shall *move* while the force continues to act. This is obvious, for if no motion exists it clearly cannot be either accelerated or maintained against resistance. The motion of the body on which a force acts being thus necessarily involved in our notion of work being done by the force, it naturally follows that, in estimating how much work is done, we should consider how much—that is to say, how far—the body moves while the force acts upon it. This agrees with the mode of estimating quantities of work in common life, as will be evident if we consider a very simple case, for instance, that of a labourer employed to carry bricks up to a scaffold: in such a case, a double number of bricks carried would represent a double quantity of work done, but so also would a doubled height of the scaffold, for whatever amount of work

is done in raising a certain number to a height of twenty feet, the same amount must be done again to raise them another twenty feet, or the amount of work done in raising the bricks forty feet is twice as great as that done when they are raised only twenty feet. It is also to be noted that no direct reference to *time* enters into the conception of a quantity of work: if we want to know how much work a labourer has done, we do not ask how long he has been at work, but what he has done, —for instance, how many bricks he has carried, and to what height;—and our estimate of the total amount of work is the same whether the man has spent hours or days in doing it.

The foregoing relations between force and work may be put into definite mathematical language as follows:—If the point of application of a force moves in a straight line, and if the part of the force resolved along this line acts in the direction of the motion, the product of that component and the length of the line is the work done by the force. If the component acts in the opposite direction to the motion, the component may be considered as a resistance and the product is work done against the resistance. Thus, in (42) if we suppose M to move up the plane from A to B, the work done by P is P × AB; the work done against the resistance Q is Q sin A × AB. It will be observed that if the forces are in equilibrium during the motion, so that the velocity of M is uniform, P equals Q sin A, and consequently the work done by the power equals that done against the resistance. Also since AB sin A equals BC, the work done against the resistance equals Q × BC. In other words, to raise Q from A to B requires the same amount of work as to raise it from C to B.

If, however, the forces are not in equilibrium, the motion of M will not be uniform, but accelerated; the work done upon it will nevertheless still be represented by the product of the force into the distance through which it acts. In order to ascertain the relation between the amount of work done and the change produced by it in the velocity of the moving mass, we must recall one or two elementary mechanical principles. Let F be the resultant force resolved along the direction of motion, and S the distance through which its point of application moves: then, according to what has been said, the work done by the force = F S. Further, it has been pointed out (29), that a constant force is measured by the momentum produced by it in a unit of time; hence, if T be the time during which the force acts, V_0 the velocity of the mass M at the beginning of this period, and V_1 the velocity at the end of it, the momentum produced during the time T is $MV_1 - MV_0$, and consequently the momentum produced in a unit of time, or, in other words, the measure of the force is—

$$F = \frac{M\,(V_1 - V_0)}{T}.$$

The distance S through which the mass M moves while its velocity changes from the value V_0 to the value V_1, is the same as if it had moved during the whole period T with a velocity equal to the average value of the varying velocity which it actually possesses. But a constant force acting upon a constant mass causes its velocity to change at a uniform rate; hence, in the present case, the average velocity is simply the arithmetical mean of the initial and final velocities, or

$$S = \tfrac{1}{2}(V_1 + V_0)T.$$

Combining this with the last equation, we get as the expression for the work done by the force F—

$$F S = \tfrac{1}{2} M (V_1^2 - V_0^2);$$

or, in words, *when a constant force acts on a mass so as to change its velocity, the work done by the force is equal to half the product of the mass into the change of the square of the velocity.*

The foregoing conclusion has been arrived at by supposing the force F to be constant, but it is easy to show that it holds good equally if F is the *average* magnitude of a force which varies from one part to another of the total distance through which it acts. To prove this, let the distance S be subdivided into a very great number n of very small parts each equal to s, so that $n\,s = S$. Then, by supposing s to be sufficiently small, we may without any appreciable error consider the force as constant within each of these intervals and as changing suddenly as its point of application passes from one interval to the next. Let $F_1, F_2, F_3 \ldots\ldots F_n$, be the forces acting throughout the 1st, 2nd, 3rd . . . . nth interval respectively, and let the velocity at the end of the same intervals be $v_1, v_2, v_3, \ldots\ldots v_n\ (= V_1)$ respectively; then, for the work done in the successive intervals we have—

$$\begin{aligned} F_1 s &= \tfrac{1}{2} M (v_1^2 - V_0^2) \\ F_2 s &= \tfrac{1}{2} M (v_2^2 - v_1^2) \\ F_3 s &= \tfrac{1}{2} M (v_3^2 - v_2^2) \\ &\vdots \\ F_n s &= \tfrac{1}{2} M (v_n^2 - v_{n-1}^2) = \tfrac{1}{2} M (V_1^2 - v_{n-1}^2), \end{aligned}$$

or, for the total work.

$$(F_1 + F_2 + F_3 + \ldots\ldots + F_n)\, s = \tfrac{1}{2} M (V_1^2 - V_0^2);$$

where the quantity on the left-hand side of the equation may also be written $\dfrac{F_1 + F_2 + \ldots + F_n}{n}\, n\, s = F\, S$, if we put F to stand for the average (or arithmetical mean) of the forces F_1, F_2, etc.

An important special case of the application of the above formula arises when either the initial or the final velocity of the mass M is nothing, that is to say, when the effect of the force is to make a body pass from a state of rest into one of motion, or from a state of motion into one of rest. The general expression then assumes one of the following forms, namely:—

$$F\, S = \tfrac{1}{2} M V_1^2 \text{ or,}$$
$$-F\, S = \tfrac{1}{2} M V_0^2;$$

the first of which denotes the quantity of work which must be done on a body of mass M in order to give to it the velocity V_1, while the second expresses the work that must be done in order to bring the same mass to rest when it is moving with the velocity V_0, the negative sign in the latter case showing that the force here acts *in opposition* to the actual motion, and is therefore to be regarded as a resistance.

In practice, the case which most frequently occurs is where work of acceleration and work against resistance are performed simultaneously. Thus, recurring to the inclined plane already referred to in page 37; if the force P be greater than $Mg \sin A$, the body M will move up the incline with a continually increasing velocity, and if the point of application of P be displaced from A to B, the total amount of work done, namely, P. AB, consists of a portion $= Mg \sin A \,.\, AB$, done against the resistance of the weight Q or Mg, and of a portion $= (P - Mg \sin A).\ AB$ expended in accelerating the mass M. Hence, to determine the velocity v with which M arrives at the top of the incline we have the equation

$$(P - Mg \sin A)\ AB = \tfrac{1}{2} Mv^2;$$

for the portion of P which is in excess of what is required to produce equilibrium with the weight Q, namely, $P - Mg \sin A$, corresponds to the resultant force F supposed in the foregoing discussion, and A B in the distance through which this resultant force acts.

57*a*. **Unit of Work.** For strictly scientific purposes a unit of work is taken to be the work done by a unit of force when its point of application moves through one foot in the direction of its action; but, as a convenient and sufficiently accurate standard for practical purposes, the quantity of work which is done in lifting 1 pound through the height of 1 foot is commonly adopted as the unit, and this quantity of work is spoken of as one 'foot-pound.' It is, however, important to observe that the foot-pound is not perfectly invariable, since the weight of a pound, and therefore the work done in lifting it through a given height, differs at different places; being a little greater near the poles than near the equator.

58. **Energy.**—The fact that any agent is capable of doing work is usually expressed by saying that it possesses *Energy*, and the quantity of energy it possesses is measured by the amount of work it can do. For example, in the case of the inclined plane above referred to, the working power or energy of the force P is $P \times AB$; and if this force acts under the conditions last supposed, by the time its own energy is exhausted (through its point of application having arrived at B, the limit of the range through it is supposed able to act), it has conferred upon the mass M a quantity of energy equal to that which has been expended: for, in the first place, the mass M has been raised through a vertical height equal to BC, and could by falling again through the same height do an amount of work represented by $Mg \times BC$ or $Q \times BC$; and in the second place M can do work by virtue of the velocity that has been imparted to it, and can continue moving in opposition to any given resistance R through a distance S, such that

$$RS = \tfrac{1}{2} Mv^2.$$

The energy possessed by the mass M in consequence of having been raised from the ground, is commonly distinguished as *energy of position* or *potential energy*, and is measured by the product of the force tending to cause motion into the distance through which the point of application of the force is capable of being displaced in the direction in which the force acts. The energy possessed by the mass M in consequence of its velocity, is commonly distinguished as *energy of motion* or *kinetic energy*: it is measured by half the product of the moving mass into the square of its velocity.

58*a*. **Varieties of Energy.**—It will be seen, on considering the definition of *work* given above, that a force is said to do work when it produces any change in the condition of bodies, for the only changes which, according to the definition of *force* given previously (26), a force is capable of producing, are changes in the state of rest or motion of bodies and changes of their place in opposition to resistances tending to prevent motion or to produce motion in an opposite direction. There are, however, many other kinds of physical changes which can be produced under appropriate conditions, and the recent progress of investigation has shown that the conditions under which changes of all kinds occur are so far analogous to those required for the production of work by mechanical forces, that the term *work* has come to be used in a more extended sense than formerly, and is now often used to signify the production of any sort of physical change.

Thus work is said to be done when a body at a low temperature is raised to a higher temperature, just as much as when a weight is raised from a lower to a higher level; or again, work is done when any electrical, magnetic, or chemical change is produced. This extension of the meaning of the term work involves a similar extension of the meaning of *energy*, which in this wider sense may be defined as the *capacity for producing physical change*.

As examples of energy in this more general sense the following may be mentioned: (*a*) the energy possessed by gunpowder in virtue of the mutual chemical affinities of its constituents, whereby it is capable of doing work by generating heat or by acting on a cannon ball so as to change its state of rest into one of rapid motion; (*b*) the energy of a charged Leyden jar which, according to the way in which the jar is discharged, can give rise to changes of temperature, changes of chemical composition, to mechanical changes, or to changes of magnetic or electrical condition; (*c*) the energy of a red-hot ball which, amongst other effects it is capable of producing, can raise the temperature and increase the volume of bodies colder than itself, or can change ice into water or water into steam.

59. **Transformations of Energy.**—It has been found by experiment that when one kind of energy disappears or is expended, energy of some other kind is produced, and that, under proper conditions, the disappearance of any one of the known kinds of energy can be made to give rise to a greater or less amount of any other kind. One of the simplest illustrations that can be given of this transformation of energy is afforded by the oscillations of a pendulum. When the pendulum is at rest in its lowest position it does not possess any energy, for it has no power of setting either itself or other bodies in motion or of producing in them any

nd of change. In order to set the pendulum oscillating, work must be done on it, and it thereafter possesses an amount of energy corresponding the work that has been expended. When it has reached either end of s path, the pendulum is for an instant at rest, but it possesses energy y virtue of its position, and can do an amount of work while falling to s lowest position which is represented by the product of its weight into e vertical height through which its centre of gravity descends. When t the middle of its path the pendulum is passing through its position of quilibrium and has no power of doing work by falling lower, but it now ossesses energy by virtue of the velocity which it has gained, and this nergy is able to carry it up on the second side of its lowest position to a eight equal to that from which it has descended on the first side. By he time it reaches this position the pendulum has lost all its velocity, but has regained the power of falling; this, in its turn, is lost as the pendulum returns again to its lowest position, but at the same time it regains its previous velocity. Thus during every quarter of an oscillation, the nergy of the pendulum changes from potential energy or energy of osition, into actual energy or energy of motion, or *vice versâ*.

A more complex case of the transformation of energy is afforded by a hermo-electric pile, the terminals of which are connected by a conducting wire: the application of energy in the form of heat to one face f the pile gives rise to an electric current in the wire, which, in its turn, reproduces heat, or by proper arrangements can be made to produce chemical, magnetic, or mechanical effects, such as those described below in the chapters on Electricity.

It has also been found that the transformations of energy always take place according to fixed proportions. For instance, when coal or any other combustible is burned, its chemical energy, or power of combining with oxygen vanishes, and heat or thermal energy is produced, and the quantity of heat produced by the combustion of a given amount of coal is fixed and invariable. If the combustion take place under the boiler of a steam-engine, mechanical work can be obtained by the expenditure of part of the heat produced, and here again the quantitative relation between the heat expended and the work gained in place of it is perfectly constant.

60. **Conservation of Energy.**—Another result of great importance which has been arrived at by experiment is that the total amount of energy possessed by any system of bodies is unaltered by any transformations arising from the action of one part of the system upon another, and can only be increased or diminished by effects produced on the system by external agents. In this statement it is of course understood that in reckoning the sum of the energy of various kinds which the system may possess, those amounts of the different forms of energy which are mutually convertible into each other are taken as being numerically equal; or, what comes virtually to the same thing, the total energy of the system is supposed to be reduced—either actually, or by calculation from the known ratio of transformation of the various forms of energy—to energy of some one kind; then *the statement is equivalent* to this: that

the total energy of any one form to which the energy of a given system of bodies is reducible, is unalterable so long as the system is not acted on from without. Practically it is always possible, in one way or another, to convert the whole of the energy possessed by any body or system of bodies into heat, but it cannot be all converted without loss into any other form of energy; hence the principle stated at the beginning of this article can be enunciated in the closest conformity with the direct results of experiment by saying that, so long as any system of bodies is not acted on from without, the total quantity of heat that can be obtained from it is unalterable by any changes which may go on within the system itself. For instance, a quantity of air compressed into the reservoir of an air-gun possesses energy which is represented partly by the heat which gives to it its actual temperature above the absolute zero (427), and partly by the work which the air can do on expanding. This latter portion can be converted into heat in various ways, as, for example, by allowing the air to escape through a system of capillary tubes, so fine that the air issues from them without any sensible velocity; if, however, the expanding air be employed to propel a bullet from the gun, it produces considerably less heat than in the case previously supposed, the deficiency being represented for a time by the energy of the moving bullet, but reappearing in the form of heat in the friction of the bullet against the air, and when the motion of the bullet is destroyed by striking against an inelastic obstacle at the same level as the gun. But whatever the mode and however numerous the intermediate steps by which the energy of the compressed air is converted into heat, the total quantity of heat finally obtainable from it is the same.

BOOK II.

GRAVITATION AND MOLECULAR ATTRACTION.

CHAPTER I.

GRAVITY, CENTRE OF GRAVITY, THE BALANCE.

61. **Universal attraction, its laws.**—*Universal attraction* is a force in virtue of which the material particles of all bodies tend incessantly to approach each other; it is a mutual action, however, which all bodies, at rest or in motion, exert upon one another, no matter how great or how small the space between them may be, or whether this space be occupied or unoccupied by other matter.

A vague hypothesis of the tendency of the matter of the earth and stars to a common centre was adopted even by Democritus and Epicurus. Kepler assumed the existence of a mutual attraction between the sun, the earth, and the other planets. Bacon, Galileo, and Hooke, also recognised the existence of universal attraction. But Newton was the first who established the law and the universality of gravitation.

Since Newton's time the attraction of matter by matter was experimentally established by Cavendish. This eminent English physicist succeeded by means of a delicate torsion balance (83) in rendering visible the attraction between a large leaden and a small copper ball.

The attraction between any two bodies is the resultant of the attractions of each molecule of the one upon every molecule of the other according to the law of Newton, which may be thus expressed: *the attraction between two material particles is directly proportional to the product of their masses, and inversely proportional to the square of their distances asunder.* To illustrate this, we may take the case of two spheres which, owing to their symmetry, attract each other just as if their masses were concentrated in their centres. If without other alteration the mass of one sphere were doubled, tripled, etc., the attraction between them would be doubled, tripled, etc. If, however, the mass of one sphere being doubled, that of the other were increased three times, the distance between their centres remaining the same, the attraction would be increased six times. Lastly, if, without altering their masses, the distance between their centres were *increased* from 1 to 2, 3, 4, ... units, the attraction would be *diminished* to the 4th, 9th, 16th, ... part of its former intensity. In short, if we define the unit of attraction as that which would exist between two units of mass whose distance asunder was the unit of length, the attraction of two molecules, having the masses m and m', at the distance r, would be expressed by $\frac{m\,m'}{r^2}$.

62. **Terrestrial gravitation.**—The tendency of any body to fall towards the earth is due to the mutual attraction of that body and the earth; or, to terrestrial gravitation, and is, in fact, merely a particular case of universal gravitation.

At any point of the earth's surface, the direction of gravity, that is the line which a falling body describes, is called the *vertical* line. The vertical lines drawn at different points of the earth's surface converge very nearly to the earth's centre. For points situated on the same meridian the angle contained between the vertical lines equals the difference between the latitudes of those points.

The directions of the earth's attraction upon neighbouring bodies, or upon different molecules of one and the same body, must, therefore, be considered as parallel, for the two vertical lines form the sides of a triangle whose vertex is near the earth's centre, about 4,000 miles distant, and whose base is the small distance between the molecules under consideration.

A plane or line is said to be *horizontal* when it is perpendicular to the vertical line.

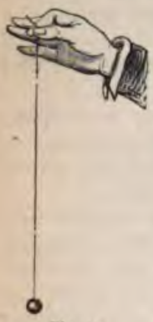


Fig. 29.

The vertical line at any point of the globe is generally determined by the *plumb-line* (fig. 29), which consists of a weight attached to the end of a string. It is evident that the weight cannot be in equilibrium, unless the direction of the earth's attraction upon it passes through the point of support, and therefore coincides with that of the string.

The horizontal plane is also determined with great ease, since it coincides, as will be afterwards shown, with the *level* surface of every liquid when in a state of equilibrium.

When the mean figure of the earth has been approximately determined, it becomes possible to compare the direction of the plumb-line at any place with that of the normal to the mean figure at that place. When any difference in these directions can be detected, it constitutes a *deviation* of the plumb-line, and is due to the attraction of some great mass of matter in the neighbourhood, such as a mountain. Thus, in the case of the mountain of Schehallien, in Perthshire, it was found by Dr. Maskelyne that the angle between the directions of two plumb-lines, one at a station to the north, and the other to the south of the mountain, was greater by 11″ 6 than the angle between the normals of the mean surface of the earth at those points; in other words, each plumb-line was deflected by about 6″ towards the mountain. By calculating the volume and mass of the mountain, it was inferred from this observation that the mean density of the mountain was to that of the earth in the ratio of 5 : 9, and that the mean density of the earth is about five times that of water,—a result agreeing pretty closely with that deduced from Cavendish's experiments referred to in the last article.

63. **Centre of gravity, its experimental determination.**—Into whatever position a body may be turned with respect to the earth, there is a certain point, invariably situated with respect to the body, through which the resultant of the attracting forces between the earth and its several molecules always passes. This point is called the *centre of gravity*; it may be within or without the body, according to the form of the latter; its existence, however, is easily established by the following considerations: Let m m', m'', m'''. . . (fig. 30) be molecules of any body. The earth's attraction upon these molecules will constitute a system of parallel forces, having a common vertical direction, whose resultant, according to (36), will be found by seeking first the resultant of the forces which act on any two molecules, m, and m', then that of this resultant, and a third force acting on m'', and so on until we arrive at the final resultant, W, representing the weight of the body, and applied at a certain point, G. If the body be now turned into the position shown in fig. 31, the molecules m, m', m''. . . . will continue to be acted on by the same forces as before, the resultant of the forces on m and m' will still pass through the same point o in the line mm', the following resultant will again pass through the same point o' in om'', and so on up to the final resultant P, which will still pass through the same point G, which is the *centre of gravity*.

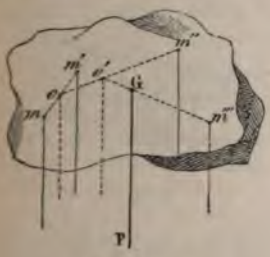


Fig. 30.

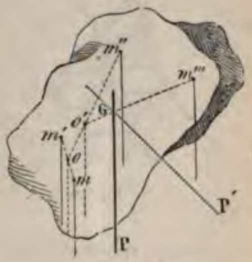


Fig. 31.

To find the centre of gravity of a body is a purely geometrical problem; in many cases, however, it can be at once determined. For instance, the centre of gravity of a right line of uniform density is the point which bisects its length; in the circle and sphere it coincides with the geometrical centre: in cylindrical bars it is the middle point of the axis. The centre of gravity of a plane triangle is in the line which joins any vertex with the middle of the opposite side, and at a distance from the vertex equal to two-thirds of this line; in a cone or pyramid it is in the line which joins the vertex with the centre of gravity of the base, and at a distance from the vertex equal to three-fourths of this line. These rules, it must be remembered, presuppose that the several bodies are of uniform density.

In order to determine experimentally the centre of gravity of a body, it is suspended by a string in two different positions, as shown in figs. 32 and

33; the point where the directions AB and CD of the string in the two experiments intersect each other is the centre of gravity required. For the resultant of the earth's attraction being a vertical force applied at the centre of gravity, the body can only be in equilibrium when this point lies vertically under the point of suspension, that is in the prolongation of the suspended string. But the centre of gravity being in AB as well as in CD must coincide with the point of intersection of these two lines.

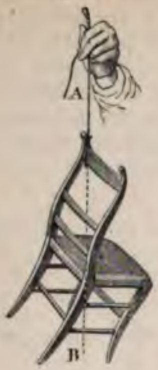


Fig. 32

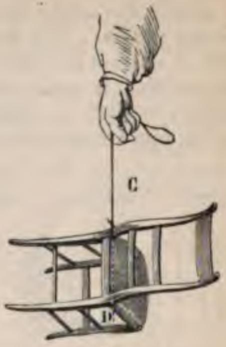


Fig. 33.

64. **Equilibrium of heavy bodies.**—Since the action of gravity upon a body reduces itself to a single vertical force applied at the centre of gravity and directed towards the earth's centre, equilibrium will be established only when this resultant is balanced by the resultant of other forces and resistances acting on the body at the fixed point through which it passes.

When only one point of the body is fixed, it will be in equilibrium if the vertical line through its centre of gravity passes through the fixed point. If more than one point is supported, the body will be in equilibrium if a vertical line through the centre of gravity passes through a point within the polygon formed by joining the points of support.

The Leaning Tower of Pisa continues to stand because the vertical line drawn through its centre of gravity passes within its base.

It is easier to stand on our feet than on stilts, because in the latter case the smallest motion is sufficient to cause the vertical line through the centre of gravity of our bodies to pass outside the supporting base, which is here reduced to a mere line joining the feet of the stilts. Again, it is impossible to stand on one leg if we keep one side of the foot and head close to a vertical wall, because the latter prevents us from throwing the body's centre of gravity vertically above the supporting base.

65. **Different states of equilibrium.**—Although a body supported by a fixed point is in equilibrium whenever its centre of gravity is in the vertical line through that point, the fact that the centre of gravity tends

incessantly to occupy the lowest possible position leads us to distinguish between three states of equilibrium—*stable, unstable, neutral.*

A body is said to be in *stable equilibrium* if it tends to return to its first position after the equilibrium has been slightly disturbed. Every body is in this state when its position is such that the slightest alteration of the same elevates its centre of gravity; for the centre of gravity will descend again when permitted, and after a few oscillations the body will return to its original position.

The pendulum of a clock continually oscillates about its position of stable equilibrium, and an egg on a level table is in this state when its long axis is horizontal. We have another illustration in the toy represented in the adjoining fig. 34. A small figure cut in ivory is made to stand on one foot at the top of a pedestal by being loaded with two leaden balls, *a*, *b*, placed sufficiently low to throw the centre of gravity, *g*, of the whole compound body below the foot of the figure. After being disturbed the little figure oscillates like a pendulum, having its point of suspension at the toe, and its centre of gravity at a lower point, *g*.

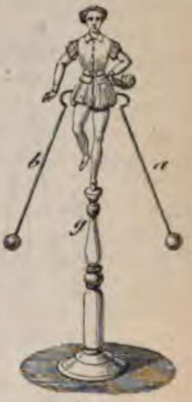


Fig. 34.

A body is said to be in *unstable equilibrium*, when after the slightest disturbance it tends to depart still more from its original position. A body is in this state when its centre of gravity is vertically above the point of support, or higher than it would be in any adjacent position of the body. An egg standing on its end, or a stick balanced upright on the finger is in this state.

Lastly, if in any adjacent position a body still remains in equilibrium, its state of equilibrium is said to be *neutral*. In this case an alteration in the position of the body neither raises nor lowers its centre of gravity. A perfect sphere resting on a horizontal plane is in this state.

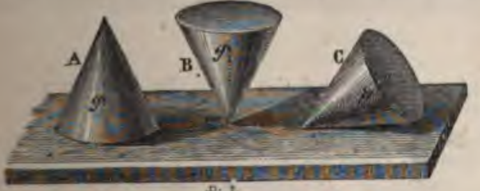


Fig. 35.

Fig. 35 represents three cones, A, B, C, placed respectively in stable, unstable, and neutral equilibrium upon a horizontal plane. The letter *g* each shows the position of the centre of gravity.

6. **The balance.**—The balance is an instrument for determining the ive weights or masses of bodies. There are many varieties.

he ordinary balance (fig. 36) consists of a lever of the first kind, called

the *beam* AB, with its fulcrum in the middle; at the extremities of t
beam are suspended two scale pans, C and D, one intended to recei

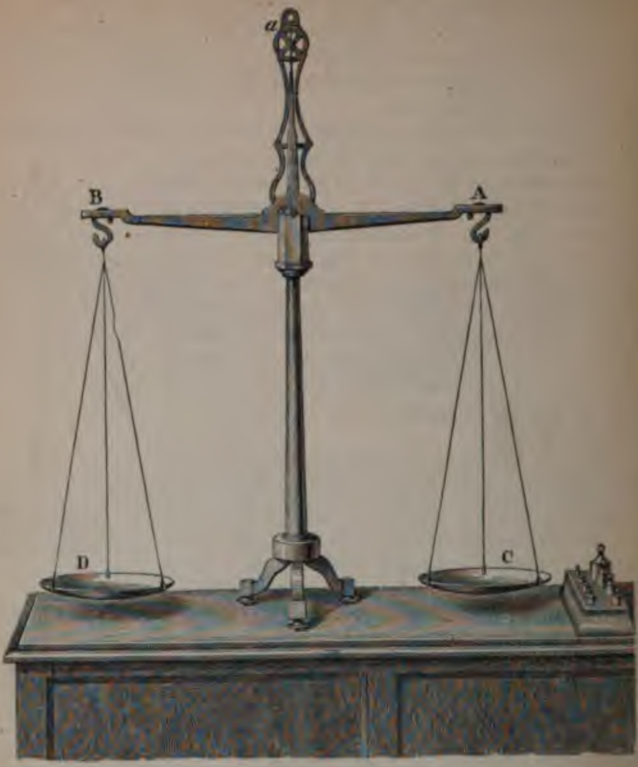


Fig. 36.

the object to be weighed, and the other the counterpoise. The fulcru
consists of a steel prism, *n*, commonly called a *knife edge*, which pass
through the beam, and rests with its sharp edge, or *axis of suspensi*
upon two supports; these are formed of agate or polished steel, in ord
to diminish the friction. A needle or pointer is fixed to the beam, a
oscillates with it in front of a graduated arc, *a*; when the beam is p
fectly horizontal the needle points to the zero of the graduated arc.

Since by (40) two equal forces in a lever of the first kind cannot
in equilibrium unless their leverages are equal, the length of the arms
and *n*B ought to remain equal during the process of weighing. To secu
this the scales are suspended from hooks, whose curved parts have sha
edges, and rest on similar edges at the ends of the beam. In this mann
the scales are supported on mere points, which remain unmoved duri

the oscillations of the beam. This mode of suspension is represented in fig. 36.

67. **Conditions to be satisfied by a balance.**—A good balance ought to satisfy the following conditions :

i. *The two arms of the beam ought to be precisely equal*, otherwise, according to the principle of the lever, unequal weights will be required to produce equilibrium. To test whether the arms of the beam are equal, weights are placed in the two scales until the beam becomes horizontal ; the contents of the scales being then interchanged, the beam will remain horizontal if its arms are equal, but if not, it will descend on the side of the longer arm.

ii. *The balance ought to be in equilibrium when the scales are empty*, for otherwise unequal weights must be placed in the scales in order to produce equilibrium. It must be borne in mind, however, that the arms are not necessarily equal, even if the beam remains horizontal when the scales are empty ; for this result might also be produced by giving to the longer arm the lighter scale.

iii. *The beam being horizontal, its centre of gravity ought to be in the same vertical line with the edge of the fulcrum, and a little below the latter*, for otherwise the beam would not be in stable equilibrium (62).

The effect of changing the position of the centre of gravity may be shown by means of a beam (fig. 37), whose fulcrum, being the nut of a screw, *a* can be raised or lowered by turning the screw-head, *b*.

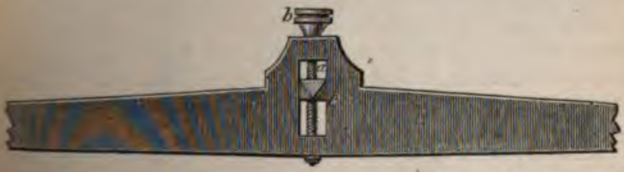


Fig. 37.

When the fulcrum is at the top of the groove *c*, in which it slides, the centre of gravity of the beam is below its edge, and the latter oscillates freely about a position of stable equilibrium. By gradually lowering the fulcrum its edge may be made to pass through the centre of gravity of the beam when the latter is in neutral equilibrium : that is to say, it no longer oscillates, but remains in equilibrium in all positions. When the fulcrum is lowered still more, the centre of gravity passes above its edge, the beam is in a state of unstable equilibrium, and is overturned by the least displacement.

68. **Delicacy of the balance.**—A balance is said to be *delicate* when a very small difference between the weights in the scales causes a perceptible deflection of the pointer.

t A and B (figs. 38 and 39) be the points from which the scale pans suspended, and C the axis of suspension of the beam. A, B, and C supposed to be in the same straight line, according to the usual ngement. Suppose weights P and Q to be in the pans suspended from A and B respectively, and let G be the centre of gravity of th beam, then the beam will come to rest in the position shown in the figur where the line DCN is vertical, and ECG is the direction of the pointer

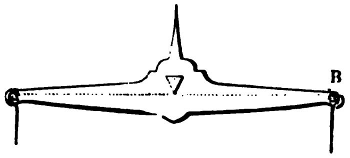


Fig. 38.

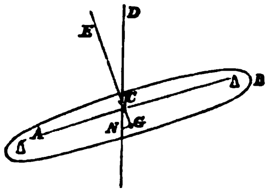


Fig. 39.

According to the above statement the greater the angle ECD for a given difference between P and Q the greater is the delicacy of the balance. Draw GN at right angles to CG.

Let W be the weight of the beam, then from the properties of the lever it follows that measuring moments with respect to C, the moment of P equals the sum of the moments of Q and W, a condition which at once leads to the relation

$$(P-Q)\,AC = W\,.\,GN$$

Now it is plain that for a given value of CG the angle GCN (that is ECD, which measures the delicacy) is greater as GN is greater : and from the formula it is plain that for a given value of P – Q we shall have GN greater as AC is greater, and as W is less. Again, for a given value of GN the angle GCN is greater as CG is less. Hence the means of rendering a balance delicate are :—

i. *To make the arms of the balance long.*

ii. *To make the weight of the beam as small as is consistent with its rigidity.*

iii. *To bring the centre of gravity of the beam a very little below the point of support.*

Moreover, since friction will always oppose the action of the force that tends to preponderate, the balance will be rendered more delicate by diminishing friction: to secure this advantage the edges from which the beam and scales are suspended are made as sharp as possible, and the supports on which they rest are very hard. And further, the pointer is made long, since its elongation renders a given deflection more perceptible by increasing the arc which its extremity describes.

69. **Physical and chemical balances.**—Fig. 40 represents one o the accurate balances ordinarily used for chemical analysis. Its sensitiveness is such that when charged with a kilogramme (1,000 grms. in each scale, an excess of a milligramme ($\frac{1}{1000}$th of a grm.) in either scale produces a very perceptible deflection of the index.

In order to protect the balance from air-currents, dust, and moisture it is always, even when weighing, surrounded by a glass case, whose fron slides up and down, to enable the operator to introduce the objects to be weighed.

In order to preserve the edge of the fulcrum as much as possible, the whole beam, BB, with its fulcrum K, can be raised from the support on

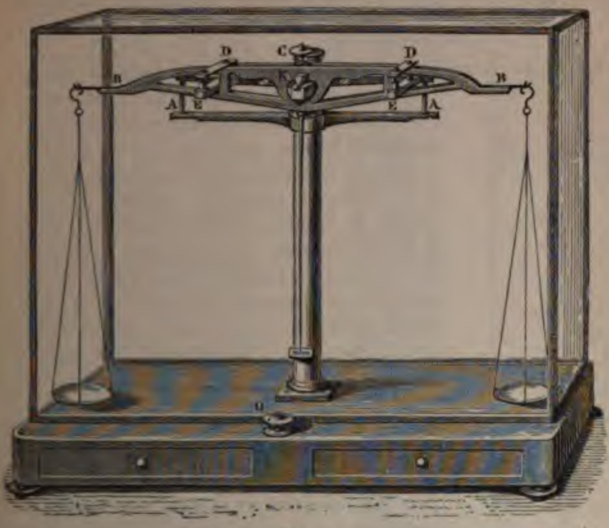


Fig. 40.

hich the latter rests by simply turning the button O outside the ase.

The horizontality of the beam is determined by means of a long index, hich points downwards to a graduated arc near the foot of the supportg pillar.

Lastly, the button C serves to alter the sensitiveness of the balance; y turning it, the centre of gravity of the beam can be made to approach r recede from the fulcrum (67).

70. **Method of double weighing.**—Notwithstanding the inaccuracy f a balance, the true weight of a body may always be determined by its eans. To do so, the body to be weighed is placed in one scale, and shot r sand poured into the other until equilibrium is produced; the body is en replaced by known weights until equilibrium is re-established. The m of these weights will necessarily be equal to the weight of the body, r, acting under precisely the same circumstances, both have produced ecisely the same effect.

CHAPTER II.

LAWS OF FALLING BODIES. INTENSITY OF TERRESTRIAL GRAV
THE PENDULUM.

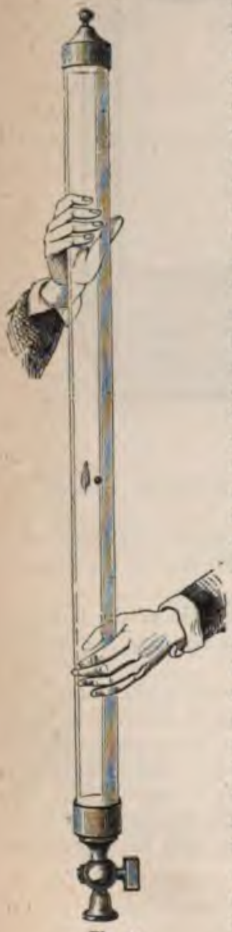


Fig. 41.

71. **Laws of falling bodies.**—Since a body falls to the grour
consequence of the earth's attraction on *each*
molecules, it follows that, everything else bein
same, all bodies, great and small, light and h
ought to fall with equal rapidity, and a lur
sand without cohesion should, during its
retain its original form as perfectly as if it
compact stone. The fact that a stone falls
rapidly than a feather is due solely to the un
resistances opposed by the air to the desce
these bodies; *in a vacuum all bodies fall*
equal rapidity. To demonstrate this by ex
ment a glass tube about two yards long (fig
may be taken, having one of its extremities
pletely closed, and a brass cock fixed to the c
After having introduced bodies of different we
and densities (pieces of lead, paper, feather,
into the tube, the air is withdrawn from it by a
pump, and the cock closed. If the tube be
suddenly reversed, all the bodies will fall eq
quickly. On introducing a little air and
inverting the tube, the lighter bodies be
slightly retarded, and this retardation incr
with the quantity of air introduced.

The resistance opposed by the air to fa
bodies is especially remarkable in the cas
liquids. The Staubbach in Switzerland is a
illustration; an immense mass of water is
falling over a high precipice, but before reac
the bottom it is shattered by the air into
finest mist. In a vacuum, however, liquids
like solids without separation of their molec
The *water hammer* illustrates this: the in
ment consists of a thick glass tube about a
long, half filled with water, the air having
expelled by ebullition previous to closing on
tremity with the blow-pipe. When such a
is suddenly inverted the water falls in one
vided mass against the other extremity of
tube, and produces a sharp dry sound, resembling that which accomp
the shock of two solid bodies.

From Newton's law (61) it follows, that when a body falls to the earth, the force of attraction which causes it to do so increases as the body approaches the earth. Unless the height from which the body falls, however, be very great, this increase will be altogether inappreciable, and the force in question may be considered as constant and continuous. If the resistance of the air were removed, therefore, the motion of all bodies falling to the earth would be uniformly accelerated, and would obey the laws already explained (46).

72. Attwood's machine.—Several instruments have been invented for illustrating and experimentally verifying the laws of falling bodies. Galileo, who discovered these laws in the early part of the seventeenth century, illustrated them by means of bodies falling down inclined planes. The great object of all such instruments is to diminish the rapidity of the fall of bodies without altering the character of their motion, for by this means their motion may not only be better observed, but it will be less modified by the resistance of the air.

The most convenient instrument of this kind is that invented by Attwood at the end of the last century, and represented in fig. 42. It consists of a stout pillar of wood, about 2½ yards high, at the top of which is a brass pulley, whose axle rests and turns upon four other wheels, called *friction wheels*, inasmuch as they serve to diminish friction. Two equal weights, M and M′, are attached to the extremities of a fine silk thread, which passes round the pulley; a timepiece, H, fixed to the pillar, is

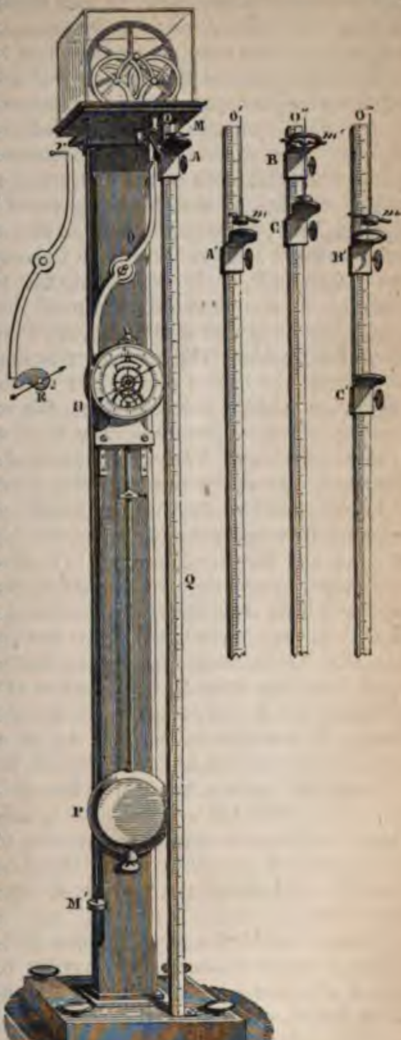


Fig. 42.

regulated by a seconds pendulum, P, in the usual way—that is to say, th oscillations of the pendulum are communicated to a ratchet, whose tw teeth, as seen in the figure, fit into those of the ratchet wheel. The axl of this wheel gives motion to the seconds hand of the dial, and also to a excentric behind the dial, as shown at E by a separate figure. This e centric plays against the extremity of a lever D, which it pushes until th latter no longer supports the small plate, i, and thus the weight M, whic at first rested on this plate, is suddenly exposed to the free action c gravity. The excentric is so constructed that the little plate i falls pre cisely when the hand of the dial points to zero.

The weights M and M′ being equal hold each other in equilibrium the weight M, however, is made to descend slowly by putting a small ba or overweight m upon it; and to measure the spaces which it describe the rod or scale, Q, is divided into feet and inches, commencing from th plate i. To complete the instrument there are a number of plates, A, A C, C′, and a number of rings, B, B′, which may be fixed by screws at an part of the scale. The plates arrest the descending weight M, the ring only arrest the bar or overweight m, which was the cause of motion, s that after passing through them, the weight M, in consequence of it inertia, will move on uniformly with the velocity it had acquired o reaching the ring. The several parts of the apparatus being described, few words will suffice to explain the method of experimenting.

Let the hand of the dial be placed behind the zero point, the lever I adjusted to support the plate i, on which the weight M with its overweigh m rests, and the pendulum put in motion. As soon as the hand of th dial points to zero the plate i will fall, the weights M and m will descenc and by a little attention and a few trials it will be easy to place a plate so that M may reach it exactly as the dial indicates the expiration of on second. To make a second experiment, let the weights M and m, th plate i, and the lever D, be placed as at first; remove the plate A, and i its place put a ring, B, so as to arrest the overweight m just when th weight M would have reached A; on putting the pendulum in motio again it will be easy, after a few trials, to put a plate, C, so that the weigh M may fall upon it precisely when the hand of the dial points to tw seconds. Since the overweight m in this experiment was arrested by th ring B at the expiration of one second, the space BC was described by M in one second purely in virtue of its own inertia, and consequently, b (32) BC will indicate the velocity of the falling mass at the expiration c one second.

Proceeding in the same manner as before, let a third experiment b made in order to ascertain the point B′ at which the weight M and arrive after the lapse of two seconds, and, putting a ring at B′, ascertai by a fourth experiment the point C′ at which M arrives alone, thre seconds after the descent commenced; B′C′ will then express th velocity acquired after a descent of two seconds. In a similar manne by a fifth and sixth experiment, we may determine the space OB described in three seconds, and the velocity B″C″ acquired during thos three seconds, and so on; we shall find that B′C′ is twice, and B″C″

three times as great as BC—in other words, that the velocities BC, B′C′, B″C″, increase in the same proportion as the times (1, 2, 3, . . . seconds) employed in their acquirement. By the definition (46), therefore, the motion is uniformly accelerated. The same experiments will also serve to verify and illustrate the four laws of uniformly accelerated motion as enunciated in (46). For example, the spaces OB, OB′, OB″, ... described from a state of rest in 1, 2, 3, ... seconds, will be found to be proportional to the numbers 1, 4, 9, . . . that is to say, to the squares of those numbers of seconds, as stated in the third law.

Lastly, if the overweight *m* be changed, the acceleration or velocity BC acquired per second will also be changed, and we may easily verify the assertion in (29), that force is proportional to the product of the mass moved into the acceleration produced in a given time. For instance, assuming the pulley to be so light that its inertia can be neglected, if *m* weighed half an ounce, and M and M′ each $15\frac{3}{4}$ ounces, the acceleration BC would be found to be six inches; whilst if *m* weighed 1 ounce, and M and M′ each $63\frac{1}{2}$ ounces, the acceleration BC would be found to be three inches.

Now in these cases the forces producing motion, that is the overweights, are in the ratio of 1 : 2; while the products of the masses and the accelerations are in the ratio of $(\frac{1}{2} + 15\frac{3}{4} + 15\frac{3}{4}) \times 6$ to $(1 + 63\frac{1}{2} + 63\frac{1}{2}) \times 3$, that is, they are also in the ratio of 1 : 2. Now the same result is obtained in whatever way the magnitudes of *m*, M, and M′ are varied, and consequently in all cases the ratio of the forces producing motion equals the ratio of the momenta generated.

73. **Morin's apparatus.**—The principle of this apparatus, the original idea of which is due to General Poncelet, is to make the body in falling trace its own path. Figure 43 gives a view of the whole apparatus, and figure 44 gives the details. The apparatus consists of a wooden framework, about 7 feet high, which holds in a vertical position a very light wooden cylinder, M, which can turn freely about its axis. This cylinder is coated with paper divided into squares by equidistant horizontal and vertical lines. The latter measure the path traversed by the body falling along the cylinder, while the horizontal lines are intended to divide the duration of the fall into equal parts.

The falling body is a mass of iron, P, provided with a pencil which is pressed against the paper by a small spring. The iron is guided in its fall by two light iron wires which pass through guide-holes on the two sides. The top of this mass is provided with a tipper which catches against the end of a bent lever, AC. This being pulled by the string K attached at A, the weight falls. If the cylinder M were fixed, the pencil would trace a straight line on it; but if the cylinder moves uniformly, the pencil traces the line *mn*, which serves to deduce the law of the fall.

The cylinder is rotated by means of a weight, Q, suspended to a cord which passes round the axle G. At the end of this is a toothed wheel, *c*, which turns two endless screws, *a* and *b*, one of which turns the cylinder, and the other, two vanes, *x* and *x*′. At the otber end is a ratchet wheel, in which fits the end of a lever, B; by pulling at a cord fixed to the other end of B, the wheel is liberated, the weight Q descends, and the whole system begins to turn. The motion is at first accelerated, but as the air offers a resistance to the vanes, which increases as the rotation becomes more rapid, the resistance finally equals the acceleration which gravity tends to impart. From this time the motion becomes uniform. This is the case when the weight Q has traversed about three-quarters its course; at this moment the weight P is detached by pulling the chord K, and the pencil then traces the curve *mn*.

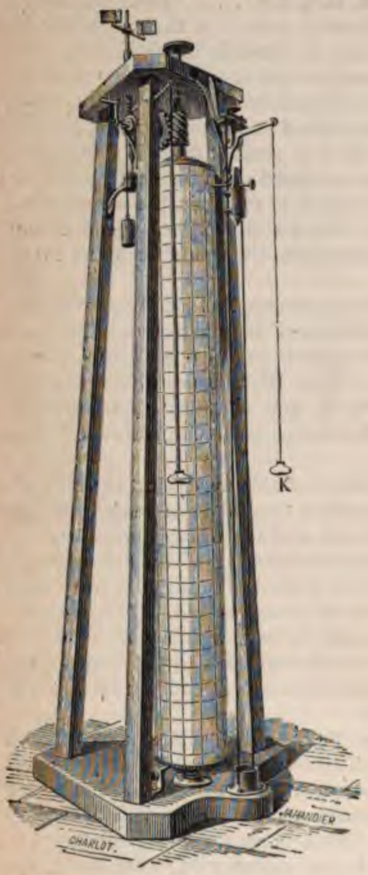


Fig. 43.

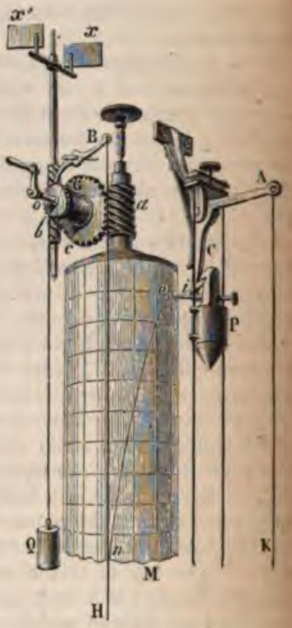


Fig. 44.

If, by means of this curve, we examine the double motion of the pencil on the small squares which divide the paper, we see that, for displacements of 1, 2, 3, ... in a horizontal direction, the displacement are 1, 4, 9 . . . . in a vertical direction. This shows that the paths traversed in the direction of the fall are directly as the squares of the lines in the direction of the rotation, which verifies the second law of falling bodies.

From the relation which exists between the two dimensions of the curve *mn*, it is concluded that this curve is a *parabola*.

74. **Length of the compound pendulum.**—The formula for the time of vibration of a simple pendulum, and the conclusions deduced from it (51) are also applicable to the compound pendulum, though in this case it will be necessary to define accurately what is meant by the *length* of such a pendulum. A compound pendulum being formed of a heavy rod terminated by a greater or less mass, it follows that the several material points of the whole system will strive to perform their oscillations in different times, their distances from the axis of suspension being different, and the more distant points requiring a longer time to complete an oscillation. From this, and from the fact that being points of the same body they must oscillate together, it follows that the motion of the points near the axis of suspension will be retarded, whilst that of the more distant points will be accelerated, and between the two extremities there will necessarily be a series of points whose motion will be neither accelerated nor retarded, but which will oscillate precisely as if they were perfectly free and unconnected with the other points of the system. These points, being equidistant from the axis of suspension, constitute a parallel axis known as the *axis of oscillation*; and it is to the distance between these two axes that the term *length of the compound pendulum* is applied : we may say, therefore, that *the length of a compound pendulum is that of the simple pendulum which would describe its oscillations in the same time.*

Huyghens, the celebrated Dutch physicist, discovered that the axes of suspension and oscillation are mutually convertible—that is to say, the time of oscillation will remain unaltered when the pendulum is suspended from its axis of oscillation. This remarkable fact enables us to determine experimentally the length of a compound pendulum. To do so the pendulum is inverted and suspended from a second and moveable axis, which, after some trials, is placed so that the inversion does not affect the number of oscillations made in a given time ; the length required is then the distance between the two axes, and on giving to l the value thus determined, the formula of (51) for the simple pendulum becomes applicable to the compound pendulum, whose oscillations, *in vacuo*, obey the same laws.

The length of the *seconds* pendulum—that is to say, of the pendulum which makes one oscillation per second—varies, of course, with the intensity of gravity ; at the level of the sea it is, according to Sabine,

39·02074 inches at the Equator (St. Thomas),
39·13983 „ at London, and
39·21469 „ at Spitzbergen.

According to the formula of (51), therefore, the accelerative effect of gravity at the above places is obtained by simply multiplying tl numbers reduced to feet by the square of 3·14159. Consequentl the space described in the first second of its motion by a body f *vacuo* from a state of rest (46) is

16·0467 feet at the Equator,
16·0956 „ at London, and
16·1264 „ at Spitzbergen.

From observations of this kind, after applying the necessary cor and taking into account the effect of rotation (77), the form of tl can be deduced.

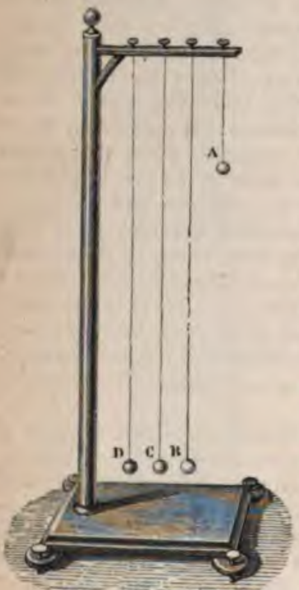


Fig 45.

5. **Verification of the laws pendulum.**—In order to verify t of the simple pendulum (51) we a pelled to employ a compound one construction differs as little as from that of the former. For this a small sphere of a very dense sul such as lead or platinum, is su from a fixed point by means of a thread. A pendulum thus forme lates almost like a simple pendulum length is equal to the distance centre of the sphere from the suspension.

In order to verify the isochro small oscillations, it is merely n to count the number of oscillatio in equal times, as the amplitudes oscillations diminish from 3 degr fraction of a degree; this number to be constant.

That the time of vibration is tional to the square root of the l verified by causing pendulums, lengths are as the numbers 1, 4, to oscillate simultaneously. Th sponding numbers of oscillations in a given time are then foun proportional to the fractions 1 $\frac{1}{2}$, $\frac{1}{3}$, etc. . . . . which shows t times of oscillation increase as the numbers 1, 2, 3, ... etc.

By taking several pendulums of exactly equal length B, C, D but with spheres of different substances, lead, copper, ivory, it that, neglecting the resistance of the air, these pendulums osc equal times, thereby showing that the accelerative effect of gr all bodies is the same at the same place.

By means of an arrangement resembling the above, Newton the fact that the *masses* of bodies are determined by the balance it will be remarked, lies at the foundation of the measure of fo

For it will be seen on comparing (50) and (51) with (47) that the law of the time of a small oscillation is obtained on the supposition that the force of gravity on all bodies is represented by Mg, in which M is determined by the balance. In order to verify this, he had made two round equal wooden boxes; he filled one with wood, and as nearly as possible in the centre of oscillation of the other he placed an equal weight of gold. He then suspended the boxes by threads eleven feet long, so that they formed pendulums exactly equal so far as weight, figure, and resistance of the air were concerned. Their oscillations were performed in exactly the same time. The same results were obtained when other substances were used, such as silver, lead, glass, sand, salt, wood, water, corn. Now all these bodies had equal weights, and if the inference that therefore they had equal masses had been erroneous by so much as the one thousandth part of the whole, the experiment would have detected it.

76. **Application of the pendulum to clocks.**—The regulation of the motion of clocks is effected by means of pendulums, that of watches by balance-springs. Pendulums were first applied to this purpose by Huyghens in 1658, and in the same year Hooke applied a spiral spring to the balance of a watch. The manner of employing the pendulum is shown in fig. 46. The pendulum rod passing between the prongs of a fork a communicates its motion to a rod b, which oscillates on a horizontal axis o. To this axis is fixed a piece mn called an *escapement* or *crutch*, terminated by two projections or *pallets*, which work alternately with the teeth of the *escapement wheel* R. This wheel being acted on by the weight tends to move continuously, let us say, in the direction indicated by the arrow-head. Now if the pendulum is at rest, the wheel is held at rest by the pallet m, and with it the whole of the clockwork and the weight. If, however, the pendulum moves and takes the position shown by the dotted line, m is raised, the wheel *escapes* from the confinement in which it was held by the pallet, the weight descends, and causes the wheel to turn until its motion is arrested by the other pallet n; which in consequence of the motion of the pendulum will be brought into contact with another tooth of the escapement wheel. In this manner the descent of the weight is alternately permitted and arrested—or, in a word, *regulated*—by the pendulum. By means of a proper train of wheelwork the motion of the escapement is communicated to the hands of the clock; and consequently their motion, also, is regulated by the pendulum.

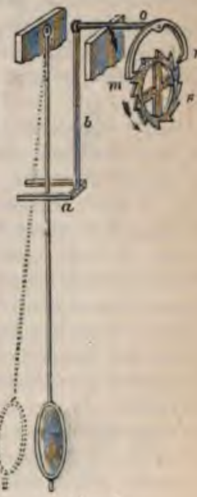


Fig. 46.

The pendulum is also used for measuring great velocities. A large block of wood weighing from 3 to 5 tons is coated with iron; against this arrangement, which is known as a *ballistic pendulum*, a shot is fired, and the deflection thereby produced is observed. From the laws of the impact of inelastic bodies, and from those of the pendulum, the velocity of the ball may be calculated from the amount of this deflection.

77. **Causes which modify the intensity of terrestrial gravitation.**—The intensity of the force of gravity at the earth's surface is modified by two causes, viz. by the form and by the rotation of the earth.

i. If the earth were a sphere of uniform density the resultant of the attractions which its parts exert on an external point would be the same as if the whole of its mass were collected at its centre, and therefore the attraction at all points of its surface would be the same. In consequence of the flattening of the earth at its poles, this is no longer exactly, but only very nearly true; and the attraction on an external point is only *nearly* inversely as the square of its distance from the earth's centre. As a further consequence of the flattening at the poles, the distance from the centre of a point on the surface decreases as we proceed from the equator to either pole; but as the distance decreases the attraction will increase, and consequently the force of gravity increases as the latitude increases, being least at the equator, and greatest at the poles. This is what would be true if, other things remaining the same, the earth were at rest.

ii. In consequence of the earth's rotation, the force of gravity is further modified. If we imagine a body relatively at rest on the equator, it really shares the earth's rotation, and describes, in the course of one day, a circle whose centre and radius are the centre and radius of the earth. Now since a body in motion tends by reason of its inertia to move in a straight line, it follows that to make it move in a circle, a force must be employed at each instant to deflect it from the tangent (49). Consequently, a certain portion of the earth's attraction must be employed in keeping the above body on the surface of the earth, and only the remainder is sensible as *weight* or *accelerating force*. It appears from calculation that on the equator the $\frac{1}{289}$th part of the earth's attraction on any body is thus employed, so that the magnitude of g at the equator is less by the $\frac{1}{289}$th part of what it would be were the earth at rest. If the body, instead of being on the equator, is in any given latitude, it will describe in one day a circle coinciding with the *parallel of latitude* on which it is situated. Now when bodies describe in the same time circles of different radii, it can be deduced from (49) that the forces required to keep them in those circles are proportional to their radii. Hence the force required in the case of a body in any given latitude is less than that required if the body were on the equator, and less as the latitude is greater, consequently were gravity diminished by the whole amount of this force the diminution would be less the nearer the body is to either pole. But since the force is produced only by an indirect action of gravity, it appears that the diminution is thereby rendered still less as the latitude is greater. On the whole, therefore, the force of gravity increases as we pass from the equator to either pole, in consequence of the rotation of the earth.

It will be observed that both causes, viz. the flattening of the earth at the poles, and its rotation, concur in producing an increase in the sensible force of gravity as the observer leaves the equator and approaches either pole.

CHAPTER III.

MOLECULAR FORCES.

78. **Nature of molecular forces.**—The various phenomena which bodies present show that their molecules are under the influence of two contrary forces, one of which tends to bring them together, and the other to separate them from each other. The first force, which is called *molecular attraction*, varies in one and the same body with the distance only. The second force, which is due to the action of heat, varies with the intensity of this agent, and with the distance. It is the mutual relation between these forces, the preponderance of the one or the other, which determines the molecular state of a body (4),—whether it be solid, liquid, or gaseous.

Molecular attraction is only exerted at infinitely small distances. Its effect is inappreciable when the distance between the molecules is appreciable. The laws which regulate this force are not known.

According to the manner in which it is regarded, molecular attraction is designated by the terms *cohesion*, *affinity*, or *adhesion*.

79. **Cohesion.**—*Cohesion* is the force which unites two molecules of the same nature; for example, two molecules of water, or two molecules of iron. Cohesion is strongly exerted in solids, less strongly in liquids, and scarcely at all in gases. Its intensity decreases as the temperature increases, because then the repulsive force due to heat increases. Hence it is that when solid bodies are heated they first liquefy, and are ultimately converted into the gaseous state, provided that heat produces in them no chemical change.

Cohesion varies not only with the nature of bodies, but also with the arrangement of their molecules; for example, the difference between tempered and untempered steel is due to a difference in the molecular arrangement produced by tempering. It is to the modifications which this force undergoes that many of the properties of bodies are due, such as tenacity, hardness, and ductility.

In large masses of liquids, the force of gravity overcomes that of cohesion. Hence liquids acted upon by the former force have no special shape; they take that of the vessel in which they are contained. But in smaller masses cohesion gets the upper hand, and liquids present then the spheroidal form. This is seen in the drops of dew on the leaves of plants; it is also seen when a liquid is placed on a solid which it does not moisten; as, for example, mercury upon wood. The experiment may also be made with water, by sprinkling upon the surface of the wood some light powder, such as lycopodium or lampblack, and then dropping some water on it. The following pretty experiment is an illustration of the force of cohesion causing a liquid to assume the spheroidal form. A saturated solution of sulphate of zinc is placed in a narrow-necked bottle and a few drops of bisulphide of carbon, coloured with iodine, made t float on the surface. If pure water be now carefully added, so as t rest on the surface of the sulphate of zinc solution, the bisulphide collect in the form of a flattened spheroid, which presents the appearance o blown coloured glass, and is larger than the neck of the bottle, provided a sufficient quantity has been taken.

80. **Affinity.**—*Chemical affinity* is the force which is exerted between molecules not of the same kind. Thus, in water, which is composed o oxygen and hydrogen, it is affinity which unites these elements, but it i cohesion which binds together two molecules of water. In compound bodies cohesion and affinity operate simultaneously, while in simple bodies or elements cohesion has alone to be considered.

To affinity are due all the phenomena of combustion, and of chemical combination and decomposition.

The causes which tend to weaken cohesion are most favourable t affinity ; for instance, the action of affinity between substances is facilitated by their division, and still more by reducing them to a liquid o gaseous state. It is most powerfully exerted by a body in its *nascent* state, that is, the state in which the body exists at the moment it is disengaged from a compound ; the body is then free, and ready to obey the feeblest affinity. An increase of temperature modifies affinity differently under different circumstances. In some cases, by diminishing cohesion, and increasing the distance between the molecules, heat promotes combination. Sulphur and oxygen, which at the ordinary temperature are without action on each other, combine to form sulphurous acid when the temperature is raised: in other cases heat tends to decompose compounds by imparting to their elements an unequal expansibility. Thus it is that many metallic oxides, as for example those of silver and mercury, are decomposed, by the action of heat, into gas and metal.

81. **Adhesion.**—The molecular attraction exerted between bodies in contact is called *adhesion.*

i. Adhesion takes place between solids. If two leaden bullets are cut with a penknife so as to form two equal and brightly polished surfaces, and the two faces are pressed and turned against each other until they are in the closest contact, they adhere so strongly as to require a force of more than 100 grammes to separate them. The same experiment may be made with two equal pieces of glass, which are polished and made perfectly plane. When they are pressed one against the other, the adhesion is so powerful that they cannot be separated without breaking. As the experiment succeeds *in vacuo*, it cannot be due to atmospheric pressure, but must be attributed to a reciprocal action between the two surfaces. The attraction also increases as the contact is prolonged, and is greater in proportion as the contact is closer.

In the operation of gluing, the pores and crevices of the fresh surfaces being filled with liquid glue, so that there is no empty space on drying, od and glue form one compact whole. In some cases the adhesion of cement is so powerful that the mass breaks more readily at other ces than at the cemented parts.

ii. Adhesion also takes place between solids and liquids. If we dip a ss rod into water, on withdrawing it a drop will be found to collect its lower extremity, and remain suspended there. As the weight of e drop tends to detach it, there must necessarily be some force superior this weight which maintains it there : this force is the force of dhesion.

iii. The force of adhesion operates, lastly, between solids and gases. If glass or metal plate be immersed in water, bubbles will be found to pear on the surface. As air cannot penetrate into the pores of the te, the bubbles could not arise from the air which had been expelled. is solely due to the layer of air which covered the plate, and *moistened* like a liquid. In many cases when gases are separated in the nascent te on the surface of metals—as in electrolysis—the layer of gas which vers the plate has such a density that it is susceptible of very energetic emical actions.

Under the heads *capillarity*, *endosmose*, *effusion*, *absorption*, and *imbi- ition*, we shall presently study a series of phenomena which are due to olecular attraction.

CHAPTER IV.

PROPERTIES PECULIAR TO SOLIDS.

82. **Various special properties.**—After having described the principal properties common to solids, liquids, and gases, we shall discuss the properties peculiar to solids. They are, *elasticity of traction*, *elasticity of torsion*, *elasticity of flexure*, *tenacity*, *ductility*, and *hardness*.

83. **Elasticity of traction.**—Elasticity, as a general property of matter, has been already mentioned (17), but simply in reference to the elasticity developed by pressure; in solids it may also be called into play by traction, by torsion, and by flexure. The definitions there given require some extension. In ordinary life we consider those bodies as highly elastic which, like caoutchouc, undergo considerable change on the application of only a small force. Yet the force of elasticity is greatest in many bodies, such as iron, which do not seem to be very elastic. For by *force of elas 'sity* is understood the force with which the displaced particles tend to revert to their original position, and which force is equivalent to that which has brought about the change. Considered from this point of view, gases have the least force of elasticity; that of liquids is considerably greater, and is indeed greater than that of many solids. Thus, the force of elasticity of mercury is greater than that of caoutchouc, glass, wood, and stone. It is, however, less than that of the other metals, with the *exception of lead.*

This seems discordant with ordinary ideas about elasticity; b must be remembered that those bodies which by the exertion of a force, undergo a considerable change, generally have also the pro of undergoing this change without losing the property of reve completely to their original state. They have a wide *limit of elast* Those bodies which require great force to effect a change are also fo most part, those on which the exertion of a force produces a perma alteration; when the force is no longer exerted, they do not compl revert to their original state.

In order to study the laws of the elasticity of traction, Savart use apparatus represented in fi It consists of a wooden su from which are suspended rods or wires taken for ex ment. At the lower extre there is a scale pan, and the wire two points, A an are marked, the distance bet which is measured by mea the *cathetometer*, before weights are added.

The *cathetometer* consis a strong brass support, divided into millimeters, which can be adjusted vertical position by mean levelling screws and the p line. A small telescope, ex at right angles to the scale be moved up and down, an provided with a vernier w measures fiftieths of a millim By fixing the telescope su sively on the two points A B, as represented in the fi the distance between points is obtained on the gr ated scale. Placing then weights in the pan, and measuring agair distance from A to B, the elongation is obtained.

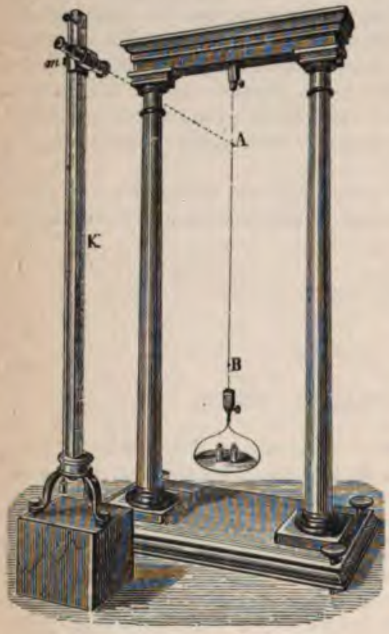


Fig. 47.

By experiments of this kind it has been ascertained that for elas of traction or pressure—

The alteration in length, within the limits of elasticity, is in propo to the length and to the load acting on the body, and is inversely a section.

It depends, moreover, on the *specific elasticity*, that is, on the ma of the body. If this coefficient be denoted by E, and if the le section, and load are respectively designated by l, s, and P, then fo alteration in length e, we have

$$e = \mathrm{E}\frac{l\mathrm{P}}{s}.$$

The following are the best values for some of the principal substances :—

Steel	21000	Silver	7400
Wrought Iron	19000	Lead	1800
Copper	12400	Wood	1100
Brass	9000	Whalebone	700
Zinc	8700	Glass	90

Thus, to double the length of a wrought iron wire a square millimeter in sections, would (if this were possible) require a weight of 19000 kilogrammes; but a weight of 15 kilogrammes produces a permanent alteration in length of $\frac{1}{1354}$th, and this is the limit of elasticity. Whalebone, on the contrary, has only a modulus of 700, and experiences a permanent change by a weight of 5 kilogrammes; its limit is, therefore, much greater than that of iron. Steel has a high modulus, along with a wide limit.

If in the above expression the sectional areas be a square millimeter, and P be one kilogramme, then

$$e = \mathrm{E}l, \text{ from which } \mathrm{E} = \frac{e}{l},$$

which expresses by what fraction the length of a bar a square millimeter in section is altered by a load of a kilogramme. This is called the *coefficient of elasticity*; it is a very small fraction, and it is therefore desirable to use its reciprocal, that is the fraction $\frac{1}{\mathrm{E}}$ as the *modulus of elasticity*; or the weight in kilogrammes which applied to a bar would elongate it by its own length, assuming it to be perfectly elastic. This cannot be observed, for no body is perfectly elastic, but it may be calculated from any accurate observations by means of the above formula.

Both calculation and experiment show that when bodies are lengthened by traction their volume increases.

From numerous experiments on the elasticity of iron, copper, and brass, made by Kohlrausch, it follows that the modulus of elasticity diminishes as the temperature rises.

84. **Elasticity of torsion.**—The laws of the torsion of wires were determined by Coulomb, by means of an apparatus called the *torsion balance* (fig. 48). It consists of a metal wire, clasped at its upper extremity in a support, A, and holding at the other extremity a metallic sphere, B, to which is affixed an index, C. Immediately below this there is a graduated circle, CD. If the needle is turned from its position of equilibrium through a certain angle which is the *angle of torsion*, the force necessary to produce this effect is called the *force of torsion*. When, after this deflection, the sphere is left to itself, the reaction of torsion produces its effect, the wire untwists itself, and the sphere rotates about its vertical axis with increasing rapidity until it reaches its position of equilibrium. It does, not, however, rest there; in virtue of its inertia it

passes this position, and the wire undergoes a torsion in the op direction. The equilibrium being again destroyed, the wire again to untwist itself, the same alteration again produced, and the needle does n at zero of the scale until after a c number of oscillations about this point been completed.

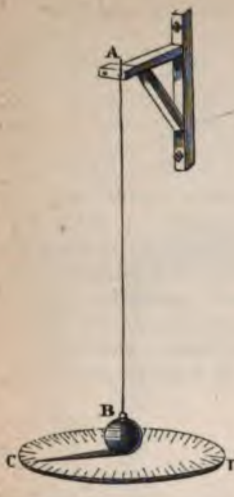


Fig. 48.

By means of this apparatus Coulomb that when the amplitude of the oscill is within certain limits, the oscillation subject to the following laws :—

I. *The oscillations are very nearl chronous.*

II. *For the same wire, the angle of t is proportional to the moment of the fo torsion.*

III. *With the same force of torsion with wires of the same diameter, the of torsion are proportional to the leng the wires.*

IV. *The same force of torsion being a to wires of the same length, the angles sion are inversely proportional to the powers of the diameters.*

Wertheim has examined the elasticity of torsion in the case of rods by means of a different apparatus, and finds that it is also s to these laws. He has further found that, all dimensions bein same, different substances undergo different degrees of torsion, and substance has its own coefficient of torsion, which is denoted by $\frac{1}{T}$

The laws of torsion may be enunciated in the formula $w = \frac{1}{T}\frac{F}{r^4}$ which w is the angle of torsion, F the moment of the force of t l the length of the wire, r its diameter, and $\frac{1}{T}$ the specific t coefficient.

85. **Elasticity of flexure.**—A solid, when cut into a thin plat fixed at one of its extremities, after having been more or less bent, to return to its original position when left to itself. This property elasticity of flexure and is very distinct in steel, caoutchouc, wood paper.

If a rectangular bar be clamped at one end and loaded at the the flexure e is represented by the formula

$$e = \frac{Pl}{bh^3 m},$$

where P is the load, l the length of the bar, b its breadth, h its v height, and m the modulus of elasticity.

The elasticity of flexure is applied in a vast variety of instances, for example, in bows, watch springs, carriage springs; in spring balances it is used to determine weights, in dynamometers to determine the force of agents in prime movers; and, as existing in wool, hair, and feathers, it is applied to domestic uses in cushions and mattresses.

Whatever be the kind of elasticity, there is, as has been already said, a limit to it—that is, there is a molecular displacement, beyond which bodies are broken, or at any rate do not regain their primitive form. This limit is affected by various causes. The elasticity of many metals is increased by *hardening*, whether by cold, by means of the draw-plate, by rolling, or by hammering. Some substances, such as steel, cast iron, and glass, become both harder and more elastic by tempering (89).

Elasticity, on the other hand, is diminished by *annealing*, which consists in raising the body to a temperature lower than that necessary for tempering, and allowing it to cool slowly. It is by this means that the elasticity of springs may be regulated at pleasure. Glass, when it is heated, undergoes a true tempering in being rapidly cooled, and hence, in order to lessen the fragility of glass objects, they are reheated in a furnace, and are carefully allowed to cool slowly, so that the particles have time to assume their most stable position.

86. **Tenacity.**—*Tenacity* is the resistance which bodies oppose to traction. It is determined in different bodies by forming them into cylindrical or prismatic wires, and ascertaining the weight necessary to break them.

Tenacity is directly proportional to the breaking weight, and inversely proportional to the area of a transverse section of the wire.

Tenacity diminishes with the duration of the traction. A small force continuously applied for a long time will often break a wire, which would not at once be broken by a larger weight.

Not only does tenacity vary with different substances, but it also varies with the form of the body. Thus, with the same sectional area, a cylinder has greater tenacity than a prism. The quantity of matter being the same, a hollow cylinder has greater tenacity than a solid one; and the tenacity of this hollow cylinder is greatest when the external radius is to the internal one in the ratio of 11 to 5.

The shape has also the same influence on the resistance to crushing, as it has on the resistance to traction. A hollow cylinder with the same mass, and the same weight, offers a greater resistance than a solid cylinder. Thus it is that the bones of animals, the feathers of birds, the stems of corn and other plants, offer greater resistance than if they were solid, the mass remaining the same.

Tenacity, like elasticity, is different in different directions in bodies. In wood, for example, both the tenacity and the elasticity are greater in the direction of the fibres than in a transverse direction. And this difference obtains in general in all bodies, the texture of which is not the same in all directions.

[illegible] gives the breaking weight in pounds for v [illegible] of a square millimeter :—

[illegible]	1·47	Copper, annealed	6		
[illegible]	2·13	„ drawn			
[illegible]	4·86	Iron, annealed	11		
[illegible]	5·19	„ drawn	14		
[illegible]	6·60	Cast steel, drawn	18		
[illegible]	9·15				
[illegible]	31·68				
[illegible]	34·58	*Wood in the direction of the fi*			
[illegible]	24·20	Mahogany			
[illegible]	61·60	Oak			
[illegible]	36·08	Beech			
[illegible]	63·80	Fir			
[illegible]	58·85	Ash			
[illegible]	77.00	Box			

[illegible] the bodies are supposed to be at the ordinary temperat [illegible] temperature the tenacity rapidly decreases. M. Seguin, [illegible] made some experiments on this point with iron [illegible] obtained the following values for the tenacity, in pound [illegible] different temperatures :—

[illegible] . at 10°, 132·0 ; at 370°, 118·8 ; at 500°, 77·0 ;
[illegible] . „ 46·2 ; „ 16·9 ; „ 0.

[illegible] *Ductility* is the property in virtue of which a g [illegible] change their forms by the action of traction or pres [illegible] bodies, such as clay, wax, etc., the application of a [illegible] sufficient to produce a change; with others, such as [illegible] the aid of heat is needed, while with the metals, [illegible] must be used, such as percussion, the draw-plate, or

[illegible] that modification of ductility which is exhibited [illegible] most malleable metal is gold, which has been be [illegible] th of an inch thick. [illegible] metal is platinum. Wollaston obtained a wire [illegible] diameter. This he effected by covering with si [illegible] of an inch in diameter, so as to obtain a cyli [illegible] only, the axis of which was of platinum. This [illegible] the form of wire as fine as possible; the two m [illegible] When this wire was afterwards treated [illegible] the silver was dissolved, and the platinum wire left int [illegible] that 1,000 yards only weighed 0·75 of a grain.

[illegible] [illegible] is the resistance which bodies offer to b [illegible] by others. It is only a relative property, for a b [illegible] in reference to one body may be soft in reference to oth [illegible] hardness of two bodies is ascertained by trying whic [illegible] scratch the other. Diamond is the hardest of all bodies, f scratches all, and is not scratched by any. The hardness of a body is expressed by referring it to a *scale of hardness* : that usually adopted is—

1. Talc
2. Rock salt
3. Calcspar
4. Fluorspar
5. Apatite
6. Felspar
7. Quartz
8. Topaz
9. Corundum
10. Diamond

Thus the hardness of a body which would scratch felspar, but would be scratched by quartz, would be expressed by the number 6·5.

The pure metals are softer than their alloys. Hence it is that for jewellery and coinage gold and silver are alloyed with copper to increase their hardness.

The hardness of a body has no relation to its resistance to compression. Glass and diamond are much harder than wood, but the latter offers far greater resistance to the blow of a hammer. Hard bodies are often used for polishing powders ; for example, emery, pumice, and tripoli. Diamond, being the hardest of all bodies, can only be ground by means of its own powder.

89. **Temper.**—By sudden cooling after they have been raised to a high temperature, many bodies acquire great hardness. This operation is called *tempering*. All cutting instruments are made of tempered steel. There are, however, some few bodies upon which tempering produces quite a contrary effect. An alloy of one part of tin and four parts of copper, called *tamtam metal*, is ductile and malleable when rapidly cooled, but hard and brittle as glass when cooled slowly.

BOOK III.

ON LIQUIDS.

CHAPTER I.

HYDROSTATICS.

90. **Object of Hydrostatics.**—The science of *hydrostatics* treats of the conditions of the equilibrium of liquids, and of the pressures they exert, whether within their own mass or on the sides of the vessels in which they are contained.

The science which treats of the motion of liquids is *hydrodynamics*, and the application of the principles of this science to conducting and raising water in pipes is known by the name of *hydraulics*.

91. **General characters of liquids.**—It has been already seen (4) that liquids are bodies whose molecules are displaced by the slightest force. Their fluidity, however, is not perfect, there is always a sufficient adherence between their molecules to produce a greater or less viscosity.

Gases also possess fluidity, but in a higher degree than liquids. The distinction between the two forms of matter is that liquids are almost incompressible and are comparatively inexpansible, while gases are eminently compressible, and expand spontaneously.

The fluidity of liquids is seen in the readiness with which they take all sorts of shapes. Their compressibility is established by the following experiment.

92. **Compressibility of liquids.**—From the experiment of the Florentine Academicians (13), liquids were for a long time regarded as being completely incompressible. Since then, researches have been made on this subject by various physicists, which have shown that liquids are really compressible.

The apparatus used for measuring the compressibility of liquids has been named the *piezometer* (πιέζω, I compress, μέτρον, measure). That shown in fig. 49 is the form invented by Oersted as improved by MM. Despretz and Saigey; it consists of a strong glass cylinder, with very thick sides and an internal diameter of about 3¼ inches. The base of the cylinder is firmly cemented into a wooden foot, and on its upper part is fitted a metallic cylinder closed by a cap which can be unscrewed. this cap there is a funnel, R, for introducing water into the cylinder, a a small barrel hermetically closed by a piston, which is moved b screw, P.

nside of the apparatus there is a glass vessel, A, containing the e compressed. The upper part of this vessel terminates in a ube, which dips under mercury, O. has been previously divided into equal capacity, and it has been d how many of these parts the ontains. The latter is ascertained the weight, P, of the mercury reservoir, A, contains, and the of the mercury contained in a mber of divisions, *n*, of the capil- If N be the number of divisions all tube contained in the whole re- have $\frac{N}{n}=\frac{P}{p}$, from which the value btained. There is further a *ma-* This is a glass tube, B, containing at one end, and the lower ex- f which dips under mercury. re is no pressure on the water in er, the tube B is completely full of hen the water within the cylinder ssed by means of the screw P, re is transmitted to the mercury, s in the tube, compressing the air ontains. A graduated scale fixed e of the tube shows the reduction , and this reduction of volume in- e pressure exerted on the liquid in the cylinder, as will be seen g of the manometer.

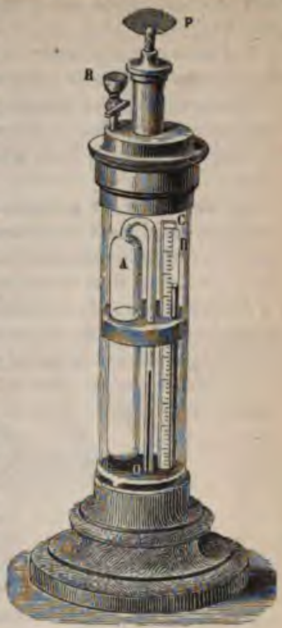


Fig. 49.

ing the experiment, the vessel A is filled with the liquid to be d, and the end dipped under the mercury. By means of the the cylinder is entirely filled with water. The screw P being d the piston moves downwards, and the pressure exerted upon is transmitted to the mercury and the air; in consequence of mercury rises in the tube, B, and also in the capillary tube. t of mercury in the capillary tube shows that the liquid in the as diminished in volume, and gives the amount of its compres- he capacity of the whole vessel A in terms of the graduated n the capillary tube has been previously determined.

first experiments, Oersted assumed that the capacity of the emained the same, its sides being compressed both internally ally by the liquid. But mathematical analysis proves that this minishes in consequence of the external and internal pressures. nd Sturm have made some experiments allowing for this change y, and have found that for a pressure equal to that of the atmo- rcury experiences a compression of 0·000005 parts of its original ater a compression of 0·00005, and ether a compression of

76

0·000133 parts of its original bulk. The compressibility of sea water is only about 0·000044 : it is not materially denser even at great depths ; thus at the depth of a mile its density would only be about $\frac{1}{130}$th the greater.

For *water and mercury* it was also found that within certain limits the decrease of volume is proportional to the pressure.

Whatever be the pressure to which a liquid has been subjected, experiment shows that as soon as the pressure is removed the liquid regains its original volume, from which it is concluded that *liquids are perfectly elastic.*

93. **Equality of pressures, Pascal's law.**—By considering liquids as perfectly fluid, and assuming them to be uninfluenced by the action of gravity, the following law has been established. It is often called Pascal's law, for it was first enunciated by him.

Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force on all equal surfaces, and in a direction at right angles to those surfaces.

To get a clearer idea of the truth of this principle, let us conceive a vessel of any given form in the sides of which are placed various cylindrical apertures, all of the same size, and closed by moveable pistons. Let us, further, imagine this vessel to be filled with liquid and withdrawn from the action of gravity ; the pistons will, obviously, have no tendency to move. If now upon the piston A (fig. 50), which has a surface *a*, a weight of P pounds be placed, it will be pressed inwards, and the pressure will be transmitted to the internal faces of each of the pistons, B, C, D, and E, which will each be forced outwards by a pressure P, their surfaces being equal to that of the first piston. Since each of the pistons undergoes a pressure P, equal to that on A, let us suppose two of the pistons united so as to constitute a surface 2*a*, it will have to support a pressure 2P. Similarly, if the piston were equal to 3*a*, it would experience a pressure of 3P ; and if its area were 100 or 1,000 times that of *a*, it would sustain a pressure of 100 or 1,000 times P. In other words, the pressure on any part of the internal walls of the vessel would be proportional to the surface.

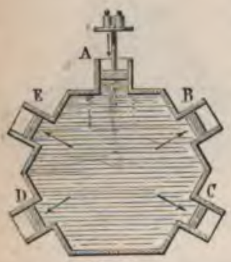


Fig. 50.

The principle of the equality of pressure is assumed as a consequence of the constitution of fluids. By the following experiment it can be shown that pressure is transmitted in all directions, although it cannot be shown that it is equally transmitted. A cylinder provided with a piston is fitted into a hollow sphere (fig. 51), in which small cylindrical jets are placed perpendicular to the sides. The sphere and the cylinder being both filled with water, when the piston is moved the liquid spouts forth from all the orifices, and not merely from that which is opposite to the piston.

The reason why a satisfactory quantitative experimental demonstration of the principle of the equality of pressure cannot be given is, that th fluence of the weight of the liquid and of the friction of the pistons nnot be eliminated.

Yet an approximate verification may be effected by the experiment presented in fig. 52. Two cylinders of different diameters are joined

Fig. 51

a tube and filled with water. On the surface of the liquid are two tons P and *p*, which hermetically close the cylinders, but move with ction. Let the area of the large ton be, for instance, thirty times t of the smaller one. That being umed, let a weight, say of two unds, be placed upon the small ton, this pressure will be transtted to the water and to the large ton, and as this pressure amounts two pounds *on each portion of its rface equal to that of the small ton*, the large piston must support upward pressure thirty times as ch, or of sixty pounds. If now this weight be placed upon the large ton, both will remain in equilibrium; but if the weight is greater or s, this is no longer the case. If S and *s* are the areas of the large and all piston respectively, and P and *p* the corresponding loads, then, $\frac{P}{p} = \frac{S}{s}$; ence $P = \frac{pS}{s}$.

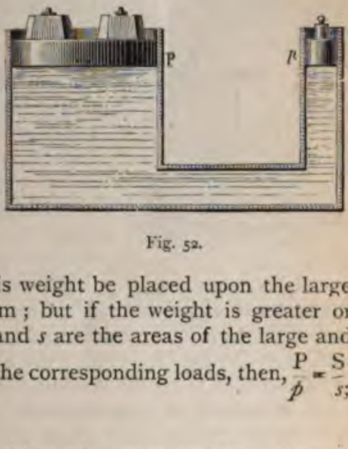


Fig. 52.

s important to observe that in speaking of the transmission of pressures to the sides of the containing vessel, these pressures must always supposed to be perpendicular to the sides; for any oblique pressure y be decomposed into two others, one at right angles to the side, and other acting parallel with the side; but as the latter has no action on side, the perpendicular one is the only one to be considered.

PRESSURE PRODUCED IN LIQUIDS BY GRAVITY.

4. **Vertical downward pressure, its laws.**—Any given liquid being state of rest in a vessel, if we suppose it to be divided into horizontal ers of the same density, it is evident that each layer supports the ght of those above it. Gravity, therefore, produces internal pressures

in the mass of a liquid which vary at different points. These pressure are submitted to the following general laws :—

I. *The pressure in each layer is proportional to the depth.*

II. *With different liquids and the same depth, the pressure is proportional to the density of the liquid.*

III. *The pressure is the same at all points of the same horizontal layer*

The first two laws are self-evident ; the third necessarily follows from the first and from Pascal's principle.

95. **Vertical upward pressure.**—The pressure which the uppe layers of a liquid exert on the lower layers causes them to exert an equa reaction in an upward direction, a necessary consequence of the principl of transmission of pressure in all directions. This upward pressure i termed the *buoyancy* of liquids ; it is very sensible when the hand i plunged into a liquid, more especially one of great density, like mercury.

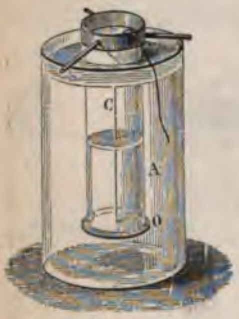


Fig. 53.

The following experiment (fig. 53) serves to exhibit the upwar pressure of liquids. A large open glass tub A, one end of which is ground, is fitted wit a ground glass disc, O, or still better with thin card or piece of mica, the weight of whic may be neglected. To the disc is fitted string, C, by which it can be held against th bottom of the tube. The whole is then immersed in water, and now the disc does not fal although no longer held by the string ; it i consequently kept in its position by the upwar pressure of the water. If water be now slowl poured into the tube, the disc will only sink when the height of the water inside the tube is equal to the height outside. It follows thence that the upward pressure on the disc is equal to the pressure of a column of water, the base of which is the internal section of the tube A, and the height, the distance from the disc to the outer surface of the liquid. Hence the *upward pressure of liquids at any point is governed by the same laws as the downward pressure.*

96. **Pressure is independent of the shape of the vessel.**—The pressure exerted by a liquid, in virtue of its weight, on any portion of the liquid, or on the sides of the vessel in which it is contained, depends on the depth and density of the liquid, but *is independent of the shape of the vessel and of the quantity of the liquid.*

This principle, which follows from the law of the equality of pressure may be experimentally demonstrated by many forms of apparatus. Th following is the one most frequently used, and is due to Haldat. I consists of a bent tube, ABC (fig. 54), at one end of which, A, is fitted stop-cock, in which can be screwed two vessels, M and P, of the sam height, but different in shape and capacity, the first being conical, an the other nearly cylindrical. Mercury is poured into the tube, ABC until its level nearly reaches A. The vessel M is then screwed on an filled with water. The pressure of the water acting on the mercur es it to rise in the tube C, and its height may be marked by means little collar, *a*, which slides up and down the tube. The level of the r in M is also marked by means of the moveable rod *o*. When this ne M is then emptied by means of the stop-cock, unscrewed and aced by P. When water is now poured in this, the mercury, which resumed its original level in the tube ABC, again rises in C, and n the water in P has the same height as it had in M, which is indi-

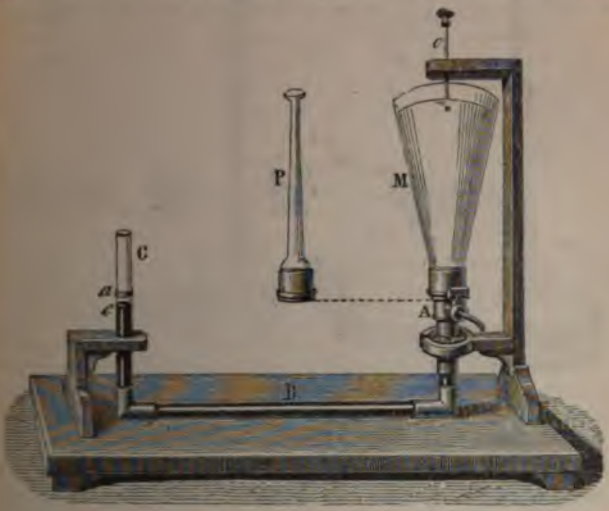


Fig. 54.

d by the rod *o*, the mercury will have risen to the height it had re, which is marked by the collar *a*. Hence the pressure on the cury in both cases is the same. This pressure is therefore indepen- of the shape of the vessels, and, consequently, also of the quantity quid. The base of the vessel is obviously the same in both cases ; it e surface of the mercury in the interior of the tube A.

nother mode of demonstrating this principle is by means of an ratus devised by Masson. In this (fig. 55) the pressure of the water ained in the vessel M is not exerted upon the column of mercury, as at of Haldat, but on a small disc or stop *a*, which closes a tubulure *c*, hich is screwed the vessel M. The disc is not fixed to the tubulure, s sustained by a thread attached to the end of a scale-beam. At the r end is a pan in which weights can be placed until they counter- nce the pressure exerted by the water on the stop. The vessel M g emptied is unscrewed, and replaced by the narrow tube O. This g filled to the same height as the large vessel, which is observed by s of the mark *o*, it will be observed that to keep the disc in its place the same weight must be placed in the pan as before, which leads, fore, to the same conclusion as does *Haldat's* experiment. The same result is obtained if, instead of the vertical tube P, the oblique tube Q be screwed to the tubulure.

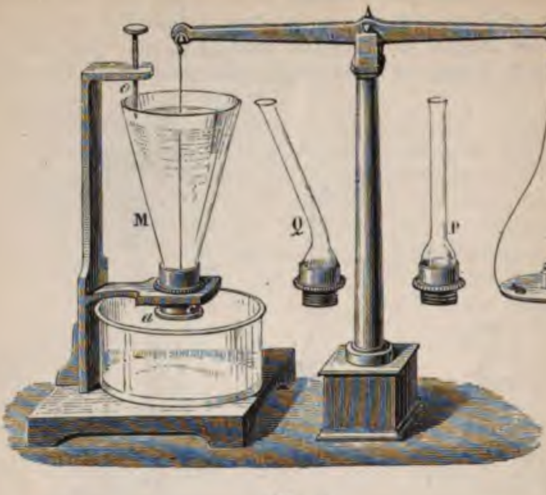


Fig. 55.

From a consideration of these principles it will be readily seen that a very small quantity of water can produce considerable pressures. Let us imagine any vessel, a cask, for example, filled with water and with a long narrow tube tightly fitted into the side. If water is poured into the tube, there will be a pressure on the bottom of the cask equal to the weight of a column of water whose base is the bottom itself, and whose height is equal to that of the water in the tube. The pressure may be made as great as we please ; by means of a narrow thread of water forty feet high, Pascal succeeded in bursting a very solidly constructed cask.

The toy known as the *hydrostatic bellows* depends on the same principle, and we shall presently see a most important application of it in the hydraulic press.

72 From the principle just laid down, the pressures produced at the bottom of the sea may be calculated. It will be presently demonstrated that the pressure of the atmosphere is equal to that of a column of seawater about thirty-three feet high. At sea the lead has frequently descended to a depth of thirteen thousand feet ; at the bottom of some seas, therefore, there must be a pressure of four hundred atmospheres.

97. **Pressure on the sides of vessels.**—Since the pressure caused by gravity in the mass of a liquid is transmitted in every direction, according to the general law of the transmission of fluid pressure, it follows that at every point of the side of any vessel a pressure is exerted, at right angles to the side, which we will suppose to be plane. The resultant of all these

pressures is the total pressure on the sides. But since these pressures increase in proportion to the depth, and also in proportion to the horizontal extent of the side, their resultant can only be obtained by calculation, which shows that the total pressure on any given portion of the side *is equal to the weight of a column of liquid, which has this portion of the side for its base, and whose height is the vertical distance from the centre of gravity of the portion to the surface of the liquid.* If the side of a vessel is a curved surface the same rule gives the pressure on the surface, but the total pressure is no longer the resultant of the fluid pressures.

The point in the side supposed plane at which the resultant of all the pressure is applied is called the *centre of pressure,* and is always below the centre of gravity of the side. For if the pressures exerted at different parts of the plane side were equal, the point of application of their resultant, the centre of pressure, would obviously coincide with the centre of gravity of the side. But since the pressures increase with the depth, the centre of pressure is necessarily below the centre of gravity. This point is determined by calculation, which leads to the following results :—

i. With a rectangular side whose upper edge is level with the water, the centre of pressure is at two-thirds of the line which joins the middle of the horizontal sides measured from the top.

ii. With a triangular side whose base is horizontal, and coincident with the level of the water, the centre of pressure is at the middle of the line which joins the vertex of the triangle with the middle of the base.

iii. With a triangular side whose vertex is level with the water, the centre of pressure is in the line joining the vertex and the middle of the base, and at three-fourths of the distance of the latter from the vertex.

98. **Hydrostatic paradox.**—We have already seen that the pressure on the bottom of a vessel depends neither on the form of the vessel nor on the quantity of the liquid, but simply on the height of the liquid above the bottom. But the pressure thus exerted must not be confounded with the pressure which the vessel itself exerts on the body which supports it. The latter is always equal to the combined weight of the liquid and the vessel in which it is contained, while the former may be either smaller or greater than this weight, according to the form of the vessel. This fact is usually termed the *hydrostatic paradox*, because at first sight it appears paradoxical.

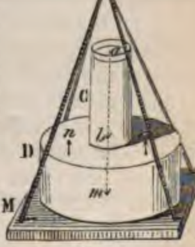


Fig. 56.

CD (fig. 56) is a vessel composed of two cylindrical parts of unequal diameters, and filled with water to *a*. From what has been said before, the bottom of the vessel CD supports the same pressure as if its diameter were everywhere the same as that of its lower part; and it would at first sight seem that the scale MN of the balance, in which the vessel CD is placed, ought to show the same weight as if there had been placed in it a cylindrical vessel having the same height of water, and having the diameter of the part D. But the pressure exerted on the bottom of the vessel is not all transmitted to the scale MN ; for the *upward* pressure upon the surface *no* of the vessel is precisely equal to the weight of the *extra* quantity of water which a cylindrical vessel would contain, and balances an equal portion of the *downward* pressure on *m*. Consequently, the pressure on the plate MN is simply equal to the weight of the vessel CD and of the water which it contains.

CONDITIONS OF THE EQUILIBRIUM OF LIQUIDS.

99. **Equilibrium of a liquid in a single vessel.**—In order that a liquid may remain at rest in a vessel of any given form, it must satisfy the two following conditions :—

I. *Its surface must be, everywhere, perpendicular to the resultant of the forces which act on the molecules of the liquid.*

II. *Every molecule of the mass of the liquid must be subject in every direction to equal and contrary pressures.*

The second condition is self-evident ; for if, in two opposite directions, the pressures exerted on any given molecule were not equal and contrary, the molecule would be moved in the direction of the greater pressure, and there would be no equilibrium. Thus the second condition follows from the principle of the equality of pressures, and from the reaction which all pressure causes on the mass of liquids.

To prove the first condition, let us suppose that *mp* is the resultant of all the forces acting upon any molecule *m* on the surface (fig. 57), and that this surface is inclined in reference to the force *mp*. The latter can consequently be decomposed into two forces, *mq* and *mf*; the one perpendicular to the surface of the liquid and the other to the direction *mp*. Now the first force, *mq*, would be destroyed by the resistance of the liquid, while the second would move the molecule in the direction *mf*, which shows that equilibrium is impossible.

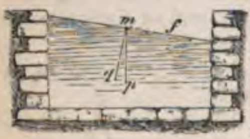


Fig. 57.

If gravity be the force acting on the liquid, the direction *mp* is vertical; hence, if the liquid is contained in a basin or vessel of small extent, the surface ought to be plane and horizontal (62), because then the direction of gravity is the same in every point. But the case is different with liquid surfaces of greater extent, like the ocean. The surface will be perpendicular to the direction of gravity; but as this changes from one point to another, and always tends towards a point near the centre of the earth, it follows that the direction of the surface of the ocean will change also, and assume a nearly spherical form.

100. **Equilibrium of the same liquid in several communicating vessels.**—When several vessels of any given form communicate with each other, there will be equilibrium when the liquid in each vessel satisfies the two preceding conditions (99), and further, *when the surfaces of the liquids in all the vessels are in the same horizontal plane.*

In the vessels ABCD (fig. 58), which communicate with each other, let us consider any transverse section of the tube *mn*; the liquid can only remain in equilibrium as long as the pressures which this section supports from *m* in the direction of *n*, and from *n* in the direction of *m*, are equal and opposite. Now it has been already proved that these pressures are respectively equal to the weight of a column of water, whose base is the supposed section, and whose height is the distance from the centre of gravity of this section to the surface of the liquid. If we conceive, then, a horizontal plane, *mn*, drawn through the centre of gravity of this section, it will be seen that there will only be equilibrium as long as the height of the liquid above this plane is the same in each vessel, which demonstrates the principle enunciated.

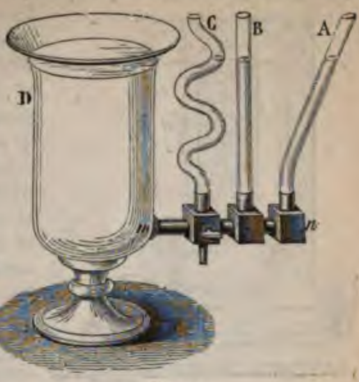


Fig. 58.

101. **Equilibrium of superposed liquids.**—In order that there should be equilibrium when several heterogeneous liquids are superposed in the same vessel, each of them must satisfy the conditions necessary for a single liquid (99); and further, *there will be stable equilibrium only when the liquids are arranged in the order of their decreasing densities from the bottom upwards.*

The last condition is experimentally demonstrated by means of the *phial of four elements.* It consists of a long narrow bottle containing mercury, water saturated with carbonate of potass, alcohol coloured red, and naphtha. When the phial is shaken the liquids mix, but when it is allowed to rest they separate; the mercury sinks to the bottom, then comes the water, then the alcohol, and then the naphtha. This is the order of the decreasing densities of the bodies. The water is saturated with carbonate of potass to prevent its mixing with the alcohol.

This separation of the liquids is due to the same cause as that which enables solid bodies to float on the surface of a liquid of greater density than their own. It is also from this principle that fresh water, at the mouths of rivers, floats for a long time on the denser salt water of the sea; and it is for the same reason that cream, which is lighter than milk, rises to the surface.

102. **Equilibrium of two different liquids in communicating vessels.**—When two liquids of different densities, which do not mix, are contained in two communicating vessels, they will be in equilibrium when, in addition to the preceding principles, they are subject to the following: *that the heights above the horizontal surface of contact of two columns of liquid in equilibrium are in the inverse ratio of their densities.*

To show this experimentally, mercury is poured into a bent glass tube, *mn*, fixed against an upright wooden support (fig. 59), and then water is poured into one of the legs, AB. The column of water, AB, pressing on the mercury at B, lowers its level in the leg AB, and raises it in th other by a quantity, CD ; so that if, when equilibrium is established, w imagine a horizontal plane, BC, to pas through B, the column of water in AB will balance the column of mercury CD If the heights of these two columns ar then measured, by means of the scales it will be found that the height of th column of water is about 13½ times tha of the height of the column of mercury We shall presently see that the density of mercury is about 13½ times that o water, from which it follows that th heights are inversely as the densities.

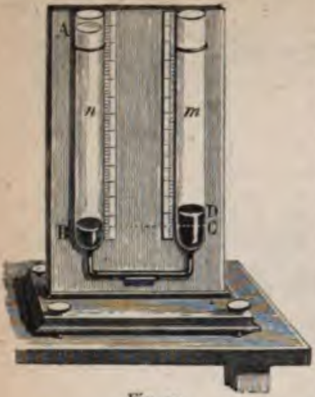


Fig. 59.

It may be added, that the equilibrium cannot exist unless there is a suffi cient quantity of the heavier liquid fo part of it to remain in *both legs* of th tube.

The preceding principle may be deduced by a very simple calculation Let d and d' be the densities of water and mercury, and h and h' thei respective heights, and let g be the force of gravity. The pressure on B will be proportional to the density of the liquid, to its height, and to the force of gravity ; on the whole, therefore, to the product dhg. Similarly, the pressure at C will be proportional to $d'h'g$. But in order to produce equilibrium, dhg must be equal to $d'h'g$, or $dh = d'h'$. This is nothing more than an algebraical expression of the above principle ; for since the two products must always be equal, d' must be as many times greater than d, as h' is less than h.

In this manner the density of a liquid may be determined. Suppose one of the branches contained water and the other oil, and their heights were, respectively 15 inches for the oil, and 14 inches for the water. The density of water being taken as unity, and that of oil being called x, we shall have

$$15 \times x = 14 \times 1 ; \text{ whence } x = \frac{14}{15} = 0{\cdot}933.$$

APPLICATIONS OF THE PRECEDING HYDROSTATIC PRINCIPLES.

103. **Hydraulic press.**—The law of the equality of pressure has received a most important application in the *hydraulic press*, a machin by which enormous pressures may be produced. Its principle is due t Pascal, but it was first constructed by Bramah in 1796.

It consists of a cylinder, B, with very strong thick sides (fig. 60), i which there is a cast iron ram, P, working water tight in the collar of th cylinder. On the ram P there is a cast iron plate on which the substanc to be pressed is placed. Four strong columns serve to support and fix second plate, Q.

y means of a leaden pipe, K, the cylinder, B, which is filled with ter, communicates with a small force pump, A, which works by means of ever, M. When the piston of this pump *p* ascends, a vacuum is pro-

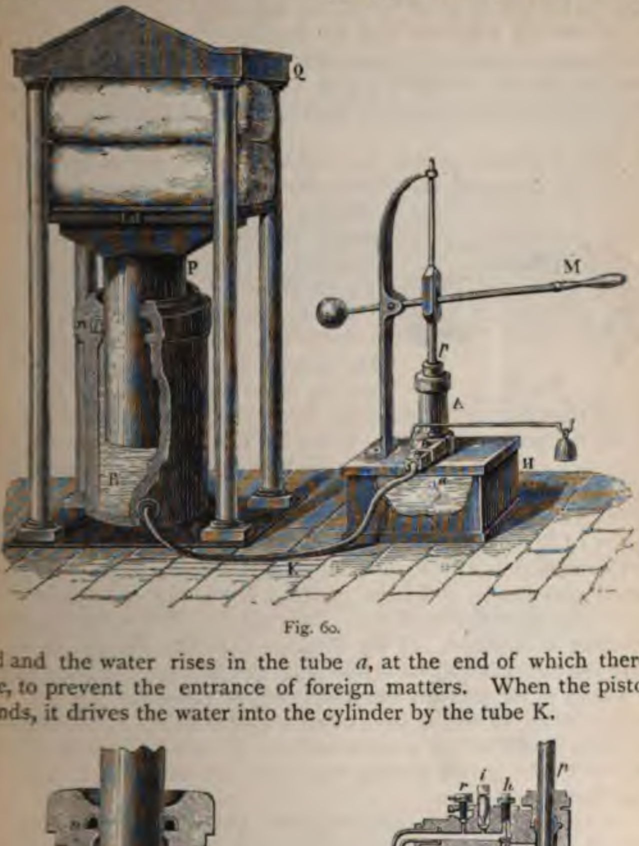


Fig. 60.

ed and the water rises in the tube *a*, at the end of which there is se, to prevent the entrance of foreign matters. When the piston *p* ends, it drives the water into the cylinder by the tube K.

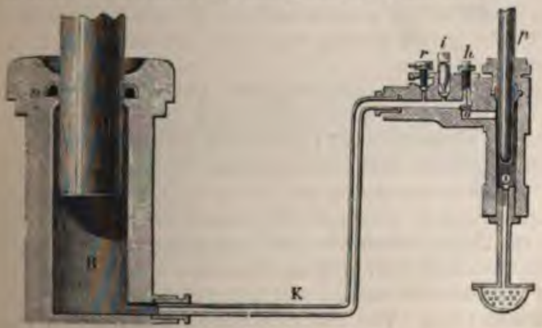


Fig. 61.

g. 61 represents a section, on a larger scale, of the system of valves ssary in working the apparatus. The valve *o*, below the piston *p*, opens when the piston rises, and closes when it descends. The valve o during this descent, is opened by the pressure of the water which passes by the pipe K. The valve *i* is a *safety valve*, held by a weight which acts on it by means of a lever. By weighting the latter to a greater or less extent the pressure can be regulated, for as soon as there is an upward pressure greater than that of the weight upon it, it opens and water escapes. A screw *r* serves to relieve the pressure, for when it is opened it affords a passage for the efflux of the water in the cylinder B.

A most important part is the leather collar, *n*, the invention of which by Bramah removed the difficulties which had been experienced in making the large ram work water-tight when submitted to great pressures. It consists of a circular piece of stout leather, fig. 62, saturated with oil so as to be impervious to water, in the centre of which a circular hole is cut. This piece is bent, so that a section of it represents a reversed U, and is fitted into a groove *n* made in the neck of the cylinder. This collar being concave downwards, in proportion as the pressure increases it fits the more tightly against the ram P on one side and the neck of the cylinder on the other, and quite prevents any escape of water.

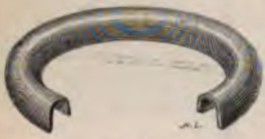


Fig. 62.

The pressure which can be obtained by this press depends on the relation of the piston P to that of the piston *p*. If the former has a transverse section fifty or a hundred times as large as the latter, the upward pressure on the large piston will be fifty or a hundred times that exerted upon the small one. By means of the lever M an additional advantage is obtained. If the distance from the fulcrum to the point where the power is applied is five times the distance from the fulcrum to the piston *p*, the pressure on *p* will be five times the power. Thus, if a man acts on M with a force of sixty pounds, the force transmitted by the piston *p* will be 300 pounds, and the force which tends to raise the piston P will be 30,000 pounds, supposing the section of P is a hundred times that of *p*.

The hydraulic press is used in all cases in which great pressures are required. It is used in pressing cloth and paper, in extracting the juice of beetroot, in expressing oil from seeds, and in curving iron plates; it also serves to test the strength of cannon, of steam boilers, and of chain cables. The parts composing the tubular bridge which spans the Menai Straits were raised by means of an hydraulic press. The cylinder of this machine, the largest which has ever been constructed, was nine feet long and twenty-two inches in internal diameter; it was capable of raising a weight of two thousand tons.

104. **Water level.**—The *water level* is an application of the conditions of equilibrium in communicating vessels. It consists of a metal tube bent at both ends, in which are fitted glass tubes D and E (fig. 63). It is placed on a tripod, and water poured in until it rises in both legs

When the liquid is at rest, the level of the water in both tubes is the same—that is, they are both in the same horizontal plane.

This instrument is used in levelling, or ascertaining how much one point is higher than another. If, for example, it is desired to find the difference between the heights of B and A, a *levelling-staff* is fixed on the latter place. This staff consists of a rule formed of two sliding pieces of wood, and supporting a piece of tin plate M, in the centre of which there is a mark. This staff being held vertically at A, an observer looks at it through the level along the surfaces D and E, and directs the holder to raise or lower the slide until the mark is in the prolongation of the line DE. The height AM is then measured, and subtracting it from the height of the level, the height of the point A above B is obtained.

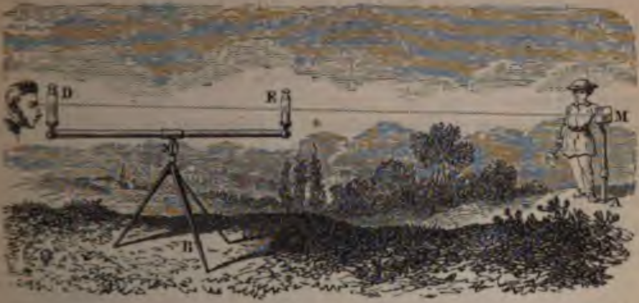
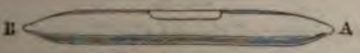


Fig. 63.

105. **Spirit level.**—The *spirit level* is both more delicate and more accurate than the water level. It consists of a glass tube, AB (fig. 64), very slightly curved, that is, the tube, instead of being a true cylinder as it seems to be, is in fact slightly curved in such a manner that its axis is an arc or a circle of very large radius; it is filled with spirit with the exception of a bubble of air, which tends to occupy the highest part. The tube is placed in a brass case, CD (fig. 65), which is so arranged that when it is in a perfectly horizontal position the bubble of air is exactly between the two points marked in the case.

Fig. 64.



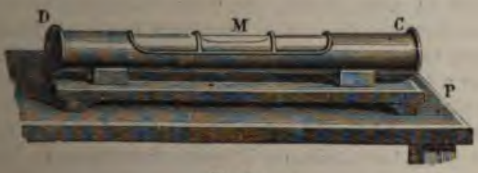


Fig. 65.

To take levels with this apparatus, it is fixed on a telescope, which can consequently be placed in a horizontal position.

106. **Artesian wells.**—All natural collections of water exemplify the tendency of water to find its level. Thus, a group of lakes, such as the great lakes of North America, may be regarded as a number of vessels in communication, and consequently the waters tend to maintain the same level in all. This, too, is the same with the source of a river and the sea, and as the latter is on the lower level, the river continually flows down to the sea along its *bed*, which is, in fact, the means of communication between the two.

Perhaps the most striking instance of this class of natural phenomena is that of *artesian wells*. These wells derive their name from the province of Artois, where it has long been customary to dig them, and from whence their use in other parts of France and Europe was derived. It seems, however, that at a very remote period wells of the same kind were dug in China and Egypt.

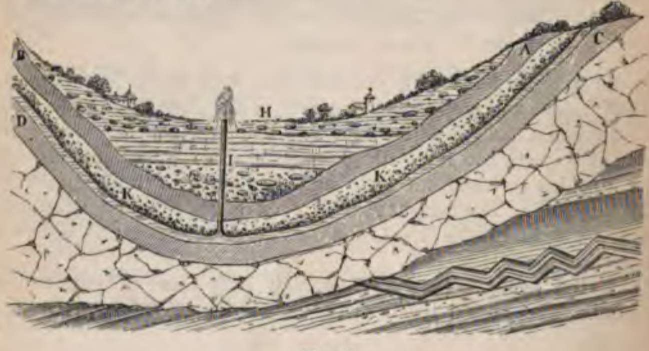


Fig. 66.

To understand the theory of these wells, it must be premised that the strata composing the earth's crust are of two kinds: the one *permeable* to water, such as sand, gravel, etc.; the others *impermeable*, such as clay. Let us suppose, then, a geographical basin of greater or less extent, in which the two impermeable layers AB, CD (fig. 66), enclose between them a permeable layer KK. The rain-water falling on the part of this layer which comes to the surface, which is called the *outcrop*, will filter through it, and following the natural fall of the ground will collect in the hollow of the basin, whence it cannot escape owing to the impermeable strata above and below it. If now a vertical hole I be sunk down to the water-bearing stratum, the water striving to regain its level will spout out to a height which depends on the difference between the levels of the outcrop and of the point at which the perforation is made.

The waters which feed artesian wells often come from a distance of sixty or seventy miles. The depth varies in different places. The well at Grenelle is 1,800 feet deep; it gives 656 gallons of water in a minute, and is one of the deepest and most abundant which have been made. The temperature of the water is 27° C. It follows from the law of the increase of temperature with the increasing depth below the surface of the ground, that, if this well were 210 feet deeper, the water would have all the year round a temperature of 32° C., that is, the ordinary temperature of baths.

BODIES IMMERSED IN LIQUIDS.

107. **Pressure supported by a body immersed in a liquid.**— When a solid is immersed in a liquid, every portion of its surface is submitted to a perpendicular pressure, which increases with the depth. If we imagine all these pressures decomposed into horizontal and vertical pressures, the first set are in equilibrium. The vertical pressures are obviously unequal, and will tend to move the body upwards.

Let us imagine a cube immersed in a mass of water (fig. 67), and that four of its edges are vertical. The pressures upon the four vertical faces being, clearly, in equilibrium, we need only consider the pressures exerted on the horizontal faces A and B. The first is pressed downwards by a column of water, whose base is the face A, and whose height is AD, the lower face B is pressed upwards by the weight of a column of water whose base is the face itself, and whose height is BD (94). The cube, therefore, is urged upwards by a force equal to the difference between these two pressures, which latter is manifestly equal to the weight of a column of water having the same base and the same height as this cube. *Consequently, this upward pressure is equal to the weight of the volume of water displaced by the immersed body.*

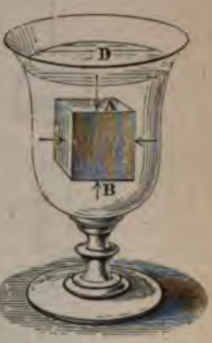


Fig. 67.

We shall readily see from the following reasoning that every body immersed in a liquid is pressed upwards by a force equal to the weight of the displaced liquid. In a liquid at rest, let us suppose a portion of it of any given shape, regular or irregular, to become solidified, without either increase or decrease of volume. The liquid thus solidified will remain at rest, and therefore must be acted upon by a force equal to its weight, and acting vertically upward through its centre of gravity; for otherwise motion would ensue. If in the place of the solidified water we imagine a solid of another substance of exactly the same volume and shape, it will necessarily receive the same pressures from the surrounding liquid as the solidified portion did; hence, like the latter, it will sustain the pressure of a force acting vertically upward through the centre of gravity of the displaced liquid, and equal to the weight of the displaced liquid. If, as almost invariably happens, the liquid is of uniform density, the centre of gravity of the displaced liquid means the centre of gravity of the immersed part of the body *supposed to be of uniform density.* This distinction is sometimes of importance; for example, if a sphere is composed of a hemisphere of iron and another of wood, its centre of gravity would not coincide with its geometrical centre; but if it were placed under water, the centre of gravity of the displaced water would be at the geometrical centre, that is, will have the same position as the centre of gravity of the sphere if of uniform density.

108. **Principle of Archimedes.**—The preceding principles prove that every body immersed in a liquid is submitted to the action of two forces; gravity which tends to lower it, and the buoyancy of the liquid which tends to raise it with a force equal to the weight of the liquid displaced.

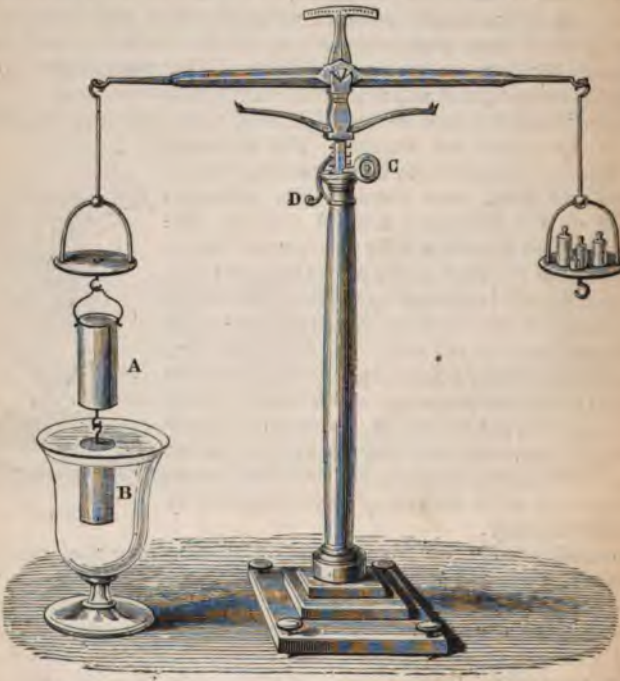


Fig. 68.

The weight of the body is either totally or partially overcome by this buoyancy, from which it is concluded that *a body immersed in a liquid loses a part of its weight equal to the weight of the displaced liquid.*

This principle, which is the basis of the theory of immersed and floating bodies, is called the principle of Archimedes, after the discoverer. It may be shown experimentally by means of the *hydrostatic balance* (fig. 68). This is an ordinary balance, each pan of which is provided with a hook; the beam can be raised by means of a toothed rack, which is worked by a little pinion, C. A catch, D, holds the rack when it has been raised. The beam being raised, a hollow copper cylinder, A, is suspended to one of the pans, and below this a solid cylinder, B, whose volume is exactly equal to the capacity of the first cylinder; lastly, an equipoise is placed in the other pan. If now the hollow cylinder be filled with water the equilibrium is disturbed; but if at the same time the beam is lowered so that the solid cylinder B becomes immersed in a vessel of water placed beneath it, the equilibrium will be restored. By being immersed in water, the cylinder B loses a portion of its weight equal to that of the water in the cylinder A. Now as the capacity of the cylinder A is exactly equal to the volume of the cylinder B, the principle which has been before laid down is proved.

109. **Determination of the volume of a body.**—The principle of Archimedes furnishes a method for obtaining the volume of a body of any shape, provided it is not soluble in water. The body is suspended by a fine thread to the hydrostatic balance, and is weighed first in the air, and then in distilled water at 4° C. The loss of weight is the weight of the displaced water, from which the volume of the displaced water is readily calculated. But this volume is manifestly that of the body itself. Suppose, for example, 155 grammes is the loss of weight. This is consequently the weight of the displaced water. Now it is known that a gramme is the weight of a cubic centimeter of water at 4°; consequently, the volume of the body immersed is 155 cubic centimeters.

110. **Equilibrium of floating bodies.**—A body when floating is acted on by two forces, namely, its weight, which acts vertically downward through its centre of gravity, and the resultant of the fluid pressures, which (104) acts vertically upward through the centre of gravity of the fluid displaced; but if the body is at rest these two forces must be equal, and act in opposite directions; whence follow the conditions of equilibrium, namely:—

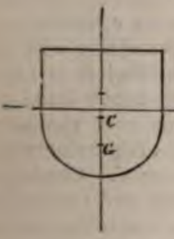


Fig. 69.

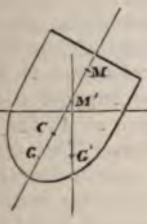


Fig. 70.

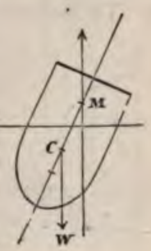


Fig. 71.

i. *The floating body must displace a volume of liquid whose weight equals that of the body.*

ii. *The centre of gravity of the floating body must be in the same vertical line with that of the fluid displaced.*

Thus in fig. 69, if C is the centre of gravity of the body and G that of the displaced fluid, the line GC must be vertical, since when it is so the weight of the body and the fluid pressure will act in opposite directions along the same line, and will be in equilibrium if equal. It is convenient with reference to the subject of the present article, to speak of the line CG produced as the axis of the body.

Next let it be enquired whether the equilibrium be stable or unstable. Suppose the body to be turned through a small angle (fig. 70) so that the axis takes a position inclined to the vertical. The centre of gravity of the displaced fluid will no longer be G, but some other point G′. And since the fluid pressure acts vertically upward through G′, its direction will cut the axis in some point M′, which will generally have different positions according as the inclination of the axis to the vertical is greater or smaller. If the angle is indefinitely small, M′ will have a definite position M, which always admits of determination, and is called the *metacentre.*

If we suppose M to be above C, an inspection of fig. 71 will show that when the body has received an indefinitely small displacement the weight of the body W and the resultant of the fluid pressures R tends to bring the body back to its original position, that is, in this case the equilibrium is stable (65). If, on the contrary, M is below C, the forces tend to cause the axis to deviate farther from the vertical, and the equilibrium is unstable. Hence the rule,

iii. *The equilibrium of a floating body is stable or unstable according as the metacentre is above or below the centre of gravity.*

The determination of the metacentre can rarely be affected except by means of a somewhat difficult mathematical process. When, however, the form of the immersed part of a body is spherical it can be readily determined, for since the fluid pressure at each point converges to the centre, and continues to do so when the body is slightly displaced, their resultant must in all cases pass through the centre, which is therefore the metacentre. To illustrate this: let a spherical body float on the surface of a liquid (fig. 72), then its centre of gravity and the metacentre both coinciding with the geometrical centre C its equilibrium is neutral (65); now suppose a small heavy body to be fastened at P, the summit of the vertical diameter. The centre of gravity will now be at some point G above C. Consequently, the equilibrium is unstable, and the sphere, left to itself, will instantly turn over and will rest when P is the lower end of a vertical diameter.

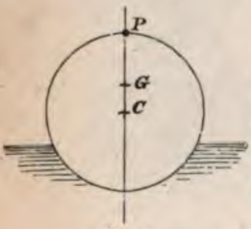


Fig. 72.

On investigating the position of the metacentre of a cylinder, it is found that when the ratio of the radius to the height is greater than a certain quantity, the position of stable equilibrium is that in which the axis is vertical; but if it be less than that quantity, the equilibrium is stable when the axis is horizontal. For this reason the stump of a tree floats lengthwise, but a thin disc of wood floats flat on the water.

Hence, also, if it is required to make a cylinder of moderate length float with its axis vertical, it is necessary to load it at the lower end. By so doing its centre of gravity is brought below the metacentre.

e determination of the metacentre and of the centre of gravity is of importance in the stowage of vessels, for on their relative positions ability depends.

. **Cartesian diver.**—The different effects of suspension, immersion, oating are reproduced by means of a well-known hydrostatic toy, *rtesian diver* (fig. 73). It consists of a glass cylinder nearly full of on the top of which a brass cap, provided with a piston, is herme- fitted. In the liquid there is a little porcelain figure attached to ow glass ball *a*, which contains air and water, and floats on the e. In the lower part of this ball there is a little hole by which can enter or escape, according as the air in the interior is more or ompressed. The quantity of water in the globe is such that very nore is required to make it sink. If the piston be slightly lowered, r is compressed, and this pressure is transmitted to the water of ssel and the air in the bulb. The conse- e is, that a small quantity of water pene- into the bulb, which therefore becomes r and sinks. If the pressure is relieved, in the bulb expands, expels the excess of which had entered it, and the apparatus now lighter, rises to the surface. The ex- ent may also be made, by replacing the cap and piston by a cover of sheet india , which is tightly tied over the mouth : his is pressed by the hand the same effects oduced.

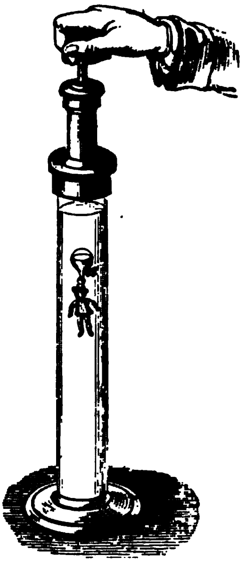


Fig. 73.

Swimming bladder of fishes.—Most have an air-bladder below the spine, which ed the *swimming bladder.* The fish can ess or dilate this at pleasure by means of a lar effort, and produce the same effects as just described—that is, it can either rise k in water.

Swimming.—The human body is lighter, e whole, than an equal volume of water; sequently floats on the surface and still in sea-water, which is heavier than fresh The difficulty in swimming consists not ch in floating, as in keeping the head above so as to breathe freely. In man the head is heavier than the lower and consequently tends to sink, and hence swimming is an art requires to be learned. With quadrupeds, on the contrary, the being less heavy than the posterior parts of the body, remains above without any effort, and these animals therefore swim naturally.

SPECIFIC GRAVITY—HYDROMETERS.

. **Determination of specific gravities.**—It has been already ned (24) that the specific gravity of a body, whether solid or liquid, is the number which expresses the relation of the weight of a given volume of this body, to the weight of the same volume of distilled water at a temperature of 4°. In order, therefore, to calculate the specific gravity of a body, it is sufficient to determine its weight and that of an equal volume of water, and then to divide the first weight by the second : the quotient is the specific gravity of the body.

Three methods are commonly used in determining the specific gravities of solids and liquids. These are, 1st, the method of the hydrostatic balance ; 2nd, that of the hydrometer ; and 3rd, the specific gravity flask. All three, however, depend on the same principle, that of first ascertaining the weight of a body, and then that of an equal volume of water. We shall first apply these methods to determining the specific gravity of solids, and then to the specific gravity of liquids.

115. **Specific gravity of solids.**—i. *Hydrostatic balance.* To obtain the specific gravity of a solid by the hydrostatic balance (fig. 68), it is first weighed in the air, and is then suspended to the hook of the balance and weighed in water (fig. 74). The loss of weight which it experiences is, according to Archimedes' principle, the weight of a volume of water equal to its own volume ; consequently, dividing the weight in air by the loss of weight in water, the quotient is the specific gravity required. If P is the weight of the body in air, P′ its weight in water, and D its specific gravity, P – P′ being the weight of the displaced water, we have $D = \frac{P}{P - P'}$.

It may be observed that though the weighing is performed in air, yet, strictly speaking, the quantity required is the weight of the body *in vacuo*, and when great accuracy is required, it is necessary to apply to the observed weights a correction for the weights of the unequal volumes of air displaced by the substance, and the weights in the other scale pan. It may also be remarked that the water in which bodies are weighed is, strictly speaking, distilled water at a standard temperature.

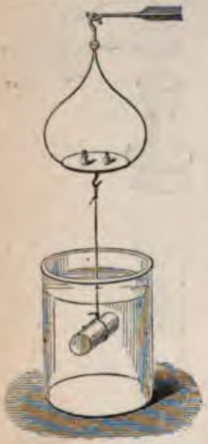


Fig. 74.

ii. *Nicholson's hydrometer.*—This apparatus consists of a hollow metallic cylinder B (fig. 75), to which is fixed a cone C, loaded with lead. The object of the latter is to bring the centre of gravity below the metacentre, so that the cylinder may float with its axis vertical. At the top is a stem, terminated by a pan, in which is placed the substance whose specific gravity is to be determined. On the stem a standard point, *o*, is marked.

The apparatus stands partly out of the water, and the first step is to ascertain the weight which must be placed in the pan in order to make the hydrometer sink to the standard point *o*. Let this weight be 125 grains, and let sulphur be the substance whose specific gravity is to be determined. The weights are then removed from the pan, and replaced by a piece of sulphur which weighs less than 125 grains, and weights added until the hydrometer is again depressed to the standard, *o*. If, for instance, it has been necessary to add 55 grains, the weight of the sulphur is evidently the difference between 125 and 55 grains, that is, 70 grains. Having thus determined the weight of the sulphur in air, it is now only necessary to ascertain the weight of an equal volume of water. To do this, the piece of sulphur is placed in the lower pan C at *m*, as represented in the figure. The whole weight is not changed, nevertheless the hydrometer no longer sinks to the standard; the sulphur, by immersion, has lost a part of its weight equal to that of the water displaced. Weights are added to the upper pan until the hydrometer sinks again to the standard. This weight, 34·4 grains, for example, represents the weight of the volume of water displaced; that is, of the volume of water equal to the volume of the sulphur. It is only necessary, therefore, to divide 70 grains, the weight in air, by 34·4 grains, and the quotient 2·03 is the specific gravity.

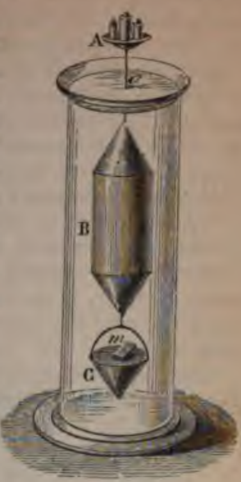


Fig. 75.

If the body in question is lighter than water it tends to rise to the surface, and will not remain on the lower pan C. To obviate this, a small moveable cage of fine wire is adjusted so as to prevent the ascent of the body. The experiment is in other respects the same.

116. **Specific gravity flask.**—When the specific gravity of a substance in a state of powder is required, it can be found most conveniently by means of the specific gravity flask. This instrument is a small flask, with a large neck fitted with a carefully ground glass stopper (fig. 76). The stopper is perforated along its axis, and the bore is continued by means of a thin tube which expands into a tube of greater diameter, as shown in the figure. On the thin tube is a mark *a*, and at each weighing the flask is filled with water exactly to the mark. This is done by filling the flask when wholly under water, and putting in the stopper while it is immersed. The flask and the tube are then completely filled, and the quantity of water in excess is removed by blotting paper. To find the specific gravity proceed as follows: Having weighed the powder, place it in one of the scale pans, and with it the flask filled exactly to *a* and carefully dried. Then balance it by placing small shot, or sand, in the other pan. Next, remove the flask and pour the powder into it, and, as before, fill it up with water to the mark *a*. On replacing the flask in the scale pan it will no longer balance the shot, since the powder has displaced a volume of water equal to its own volume. Place

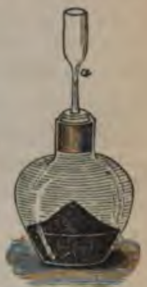


Fig. 76.

weights in the scale pan along with the flask until they balance the shot. These weights give the weight of the water displaced. Then the weight of the powder, and the weight of an equal bulk of water being known, its specific gravity is determined as before.

It is important in this determination to remove the layer of air which adheres to the powder, and unduly increases the quantity of water expelled. This is effected by placing the bottle under the receiver of an air pump, and exhausting. The same result is obtained by boiling the water in which the powder is placed.

117. **Bodies soluble in water.**— If the body, whose specific gravity is to be determined by any of these methods, is soluble in water, the determination is made in some liquid in which it is not soluble, such as oil, turpentine, or naphtha, the specific gravity of which is known. The specific gravity is obtained by multiplying the number obtained in this experiment by the specific gravity of the liquid used for the determination.

Suppose, for example, a determination of the specific gravity of potassium has been made in naphtha. For equal volumes, P represents the weight of the potassium, P′ that of the naphtha, and P″ that of water; consequently, $\frac{P}{P'}$ will be the specific gravity of the substance in reference to naphtha, and $\frac{P'}{P''}$ the specific gravity of the naphtha in reference to water. The product of these two fractions $\frac{P}{P''}$ is the specific gravity of the substance compared with water.

In determining the specific gravity of porous substances, they are varnished before being immersed in water, which renders them impervious to moisture without altering their volume.

Specific gravity of solids at zero as compared with distilled water at 4° C.

Platinum, rolled	22·069	Statuary marble	2·837
„ cast	20·337	Aluminium	2·680
Gold, stamped	19·362	Rock crystal	2·653
„ cast	19·258	St. Gobin glass	2·488
Lead, cast	11·352	China porcelain	2·385
Silver, cast	10·474	Sèvres porcelain	2·146
Bismuth, cast	9·822	Native sulphur	2·033
Copper, drawn wire	8·878	Ivory	1·917
„ cast	8·788	Anthracite	1·800
Brass	8·383	Compact coal	1·329
Steel, not hammered	7·816	Amber	1·078
Iron, bar	7·788	Melting ice	0·930
„ cast	7·207	Beech	0·852
Tin, cast	7·291	Oak	0·84
Zinc, cast	6·861	Elm	0·80
Antimony, cast	6·712	Yellow pine	0·65
Diamonds	3·531 to 3·501	Common poplar	0·389
Flint glass	3·329	Cork	0·240

118. **Specific gravity of liquids.**—i. *Method of the hydrostatic balance.* From the pan of the hydrostatic balance a body is suspended, on which the liquid whose specific gravity is to be determined exerts no chemical action; for example, a ball of platinum. This is then successively weighed in air, in distilled water, and in the liquid. The loss of weight of the body in these two liquids is noted. They represent respectively the weights of equal volumes of water and of the given liquid, and consequently it is only necessary to divide the second of them by the first to obtain the required specific gravity.

Let P be the weight of the platinum ball in air, P′ its weight in water, P″ its weight in the given liquid, and let D be the specific gravity sought. The weight of the water displaced by the platinum is P − P′ and that of the second liquid is P − P″, from which we get $D = \frac{P - P''}{P - P'}$.

ii. *Fahrenheit's hydrometer.*—This instrument (fig. 77) resembles Nicholson's hydrometer, but it is made of glass, so as to be used in all liquids. At its lower extremity, instead of a pan, it is loaded with a small bulb containing mercury. There is a standard mark on the stem.

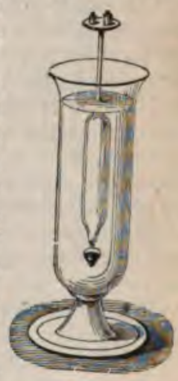


Fig. 77.

The weight of the instrument is first accurately determined in air; it is then placed in water, and weights added to the scale pan until the mark on the stem is level with the water. It follows from the first principle of the equilibrium of floating bodies, that the weight of the hydrometer, together with the weight in the scale pan, is equal to the weight of the volume of the displaced water. In the same manner, the weight of an equal volume of the given liquid is determined, and the specific gravity is found by dividing the latter weight by the former.

Neither Fahrenheit's nor Nicholson's hydrometers give such accurate results as the hydrostatic balance.

iii. *Specific gravity flask.*—This has been already described. In determining the specific gravity of a liquid, the flask is first weighed empty, and then successively, full of water, and of the given liquid. If the weight of the flask be subtracted from the two weights thus obtained, the result represents the weights of equal volumes of the liquid and of water, from which the specific gravity is obtained by division.

119. **On the observation of temperature in ascertaining specific gravities.**—As the volume of a body increases with the temperature, and as this increase varies with different substances, the specific gravity of any given body is not exactly the same at different temperatures; and consequently, a certain fixed temperature is chosen for these determina- ns. That of water, for example, has been made at 4° C., for at this int it has the greatest density. The specific gravities of other bodies e assumed to be taken at zero; but as this is not always possible, rtain corrections must be made, which we shall consider in the Book Heat.

In Liquids.

... compared with that of water ...
... unity.

[illegible]	Distilled water at 4° C.
[illegible]	" " at 0° C.
[illegible]	Claret
[illegible]	Olive oil
[illegible]	Oil of turpentine
[illegible]	Naphtha
[illegible]	Absolute alcohol
[illegible]	Ether

Use of tables of specific gravity.—Tables of specific ... various applications. In mineralogy the specific gra... ... a highly distinctive character. By means of ta... ... the weight of a body may be calculated when its v... ... conversely the volume when its weight is known.

... explaining the last-mentioned use of these tal... ... premise a statement of the connection existing b... ... length, capacity, and weight. It will manife... ... to define that which exists between th... ... arbitrary, since other measures stand to th... ... The *yard*, consisting of 36 inches, m... ... unit. Though it is essentially an ar... ... by this, that the simple pendulum ... mean second at London on the sea le... The *gallon* contains 277·274 cubic inches. A ... standard temperature weighs 10 pounds av... ..., which comes to the same thing, one ... 252·5 grains.

... the *meter* is the primary unit, and is so c... ... the length of a quadrant of the meridiar... The meter contains 10 decimeters, c... ... meters, its length equals 1·0936 yards. ... capacity is the *litre* or cubic decimeter. Th... ..., which is the weight of a cubic centime... The *kilogramme* contains 1,000 grammes ... of distilled water at 4° C. The *gramme* ...

... cubic centimeters (or decimeters) in a c... ... at 4° C., and P its weight in grammes (or ... V. Now consider a substance whose ... centimeter of this substance will wei... ... of water, and therefore V centimet... ... will weigh as much as DV centimeters of water. ... the weight of the substance in grammes we have P = DV ... V is the volume in cubic inches, and P the weight in grai... ... have P = 252·5 DV.

As an example, we may calculate the internal diameter of a glass is introduced, and the length and weight of the column at 4° C. rately determined. As the column is cylindrical, we have V = ere r is the radius, and l the length of the column in centimeters. D is the specific gravity of mercury, and P the weight of the n grammes, we have $P = \pi r^2 l D$, and therefore

$$r = \sqrt{\frac{P}{\pi D l}}$$

id l are in inches and P in grains, we shall have $P = 252{\cdot}5 \pi r^2 l D$, efore

$$r = \sqrt{\frac{P}{252{\cdot}5 \pi D l}}$$

imilar manner the diameter of very fine metallic wires can be :d.

Iydrometers with variable volume.—The hydrometers of n and Fahrenheit are called *hydrometers of constant volume, but weight*, because they are always immersed to the same extent, y different weights. There are also *hydro- f variable volume but of constant weight.* struments, known under the different names *neter, alcoholometer, lactometer, and saccha-* are not used to determine the specific f the liquids, but to show whether the acids, solutions of sugar, etc., under investigation, : or less concentrated.

Ieaumé's hydrometer.—This, which was of these instruments, may serve as a type of t consists of a glass tube (fig. 78) loaded at end with mercury, and with a bulb blown in dle. The stem, the external diameter of as regular as possible, is hollow, and the narked upon it.

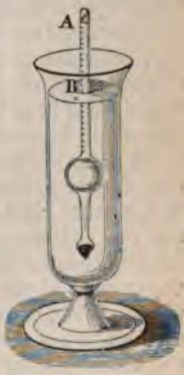


Fig. 78.

raduation of the instrument differs according uid, for which it is to be used, is heavier or ian water. In the first case, it is so constructed that it sinks in arly to the top of the stem, to a point A, which is marked zero. n of fifteen parts of salt in eighty-five parts of water is made, instruments immersed in it. It sinks to a certain point on the which is marked 15; the distance between A and B is divided qual parts, and the graduation continued to the bottom of the ometimes the graduation is on a piece of paper in the interior of

ydrometer thus graduated only serves for liquids of a greater gravity than water, such as acids and saline solutions. For ighter than water a different plan must be adopted. Beaumé zero the point to which the apparatus sank in a solution of 10 salt in 90 of water, and for 10° he took the level in distilled This distance he divided into 10°, and continued the division to f the scale.

The graduation of these hydrometers is entirely conventional, and they give neither the densities of the liquids, nor the quantities dissolved. But they are very useful in making mixtures or solutions in given proportions, the results they give being sufficiently near in the majority of cases. For instance, it is found that a well-made syrup marks 35° on Beaumé's hydrometer, from which a manufacturer can readily judge whether a syrup which is being evaporated has reached the proper degree of concentration.

123. **Gay-Lussac's alcoholometer.** — This instrument is used to determine the strength of spirituous liquors; that is, the proportion of pure alcohol which they contain. It differs from Beaumé's hydrometer in a graduation.

Mixtures of absolute alcohol and distilled water are made, containing 5, 10, 20, 30, etc., per cent. of the former. The alcoholometer is so constructed that, when placed in pure distilled water, the bottom of its stem is level with the water, and this point is zero. It is next placed in absolute alcohol, which marks 100°, and then successively in mixtures of different strengths, containing 10, 20, 30, etc., per cent. The divisions thus obtained are not exactly equal, but their difference is not great, and they are subdivided into ten divisions, each of which marks *one* per cent. of absolute alcohol in a liquid. Thus a brandy in which the alcoholometer stood at 48°, would contain 48 per cent. of absolute alcohol, and the rest would be water.

All these determinations are made at 15° C., and for that temperature only are the indications correct. For, other things being the same, if the temperature rises the liquid expands, and the alcoholometer will sink and the contrary, if the temperature falls. To obviate this error, Gay-Lussac constructed a table which for each percentage of alcohol gives the reading of the instrument for each degree of temperature from 0° up to 30°. When the exact analysis of an alcoholic mixture is to be made, the temperature of the liquid is first determined, and then the point to which the alcoholometer sinks in it. The number in the table corresponding to these data indicates the percentage of alcohol. From its giving the percentage of alcohol, this is often called the *centesimal alcoholometer*.

124. **Salimeters.**—*Salimeters*, or instruments for indicating the percentage of salt contained in a solution, are made on the principle of the centesimal alcoholometer. They are graduated by immersing them in pure water, which gives the zero, and then solutions containing different percentages, 5, 10, 20, etc., of the salt, and marking on the scale the corresponding points. These instruments are so far objectionable, that every salt requires a special instrument. Thus one graduated for common salt would give totally false indications in a solution of nitre.

Lactometers and *vinometers* are similar instruments, and are used for measuring the quantity of water which is introduced into milk or wine for the purpose of adulteration. But their use is limited, because the density of these liquids is very variable, even when they are perfectly natural and an apparent fraud may be really due to a bad natural quantity of wine or milk. *Urinometers*, which are of extensive use in medicine, are based on the same principle.

125. **Densimeter.**—The *densimeter* is an apparatus for indicating the specific gravity of a liquid. Gay-Lussac's densimeter has the same construction as Beaumé's hydrometer, but is graduated in a different manner. Rousseau's densimeter (fig. 79) is of great use in many scientific investigations, in determining the specific gravity of a small quantity of a liquid. It has the same form as Beaumé's hydrometer, but on the upper part of the stem there is a small tube, in which is placed the substance to be determined. A mark on the side of the tube indicates a measure of a cubic centimeter.

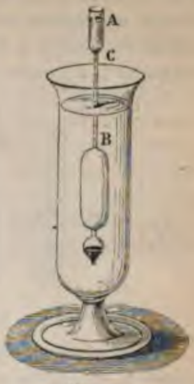


Fig. 79.

The instrument is so constructed that it sinks in distilled water to a point, B, just at the bottom of the stem. It is then filled with distilled water to the height measured on the tube, which indicates a cubic centimeter, and the point to which it now sinks is 20° The interval between 0 and 20 is divided into 20 equal parts, and this graduation is continued to the top of the scale. As this is of uniform bore each division corresponds to $\frac{1}{20}$ gramme or 0·05.

To obtain the density of any liquid, bile for example, the tube is filled with it up to the mark A; if the densimeter sinks to 20½ divisions, its weight is 0·05 + 20·5 = 1·025; that is to say, that with equal volumes the weight of water being 1, that of bile is 1·025. The specific gravity of bile is therefore 1·025.

CHAPTER II.

CAPILLARITY, ENDOSMOSE, EFFUSION, ABSORPTION, AND IMBIBITION.

126. **Capillary phenomena.**—When solid bodies are placed in contact with liquids, a class of phenomena is produced called *capillary phenomena*, because they are best seen in tubes whose diameters are comparable with the diameter of a hair. These phenomena are treated of in physics under the head of *capillarity* or *capillary attraction*: the latter expression is also applied to the force which produces the phenomena.

The phenomena of capillarity are very various, but may all be referred to the mutual attraction of the liquid molecules for each other, and to attraction between these molecules and solid bodies. The following some of these phenomena:—

When a body is placed in a liquid which wets it, for example, a glass in water, the liquid, as if not subject to the laws of gravitation, is ed upwards against the sides of the solid, and its surface, instead of being horizontal, becomes slightly concave (fig. 80). If, on the contrary, the solid is one which is not moistened by the liquid, as glass by mercury, the liquid is depressed against the sides of the solid, and assumes a convex shape, as represented in fig. 81. The surface of the liquid exhibits the same concavity or convexity against the sides of a vessel in which it is contained, according as the sides are or are not moistened by the liquid.

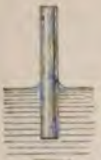


Fig. 80.

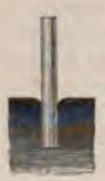


Fig. 81.

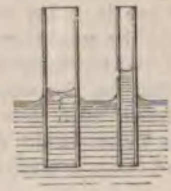


Fig. 82.

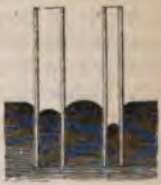


Fig. 83.

These phenomena are much more apparent when a tube of small diameter is placed in a liquid. And according as the tubes are or are not moistened by the liquid, an ascent or a depression of the liquid is produced, which is greater in proportion as the diameter is less (figs. 82 and 83).

When the tubes are moistened by the liquid, its surface assumes the form of a concave hemispherical segment, called the *concave meniscus* (fig. 82); when the tubes are not moistened, there is *convex meniscus* (fig. 83).

127. **Laws of the ascent and depression in capillary tubes.**—Gay-Lussac has shown experimentally that the elevation and depression of liquids in capillary tubes are governed by the three following laws :—

I. *When a capillary tube is placed in a liquid, the liquid is raised or depressed according as it does or does not moisten the tube.*

II. *For the same liquid the elevation varies inversely as the diameter of the tube, when the diameter does not exceed two millimeters.*

III. *The elevation varies with the nature of the liquid, and with the temperature, but is independent of the nature and thickness of the tube.*

These laws hold good *in vacuo* as well as in air.

When liquids are in tubes which they do not moisten, the depression is in the inverse ratio of the diameter of the tubes; but for tubes of the same diameter the depression depends on the substance of the tubes. For instance, in an iron tube 1 millimeter in diameter, the depression of mercury is 1·226 millimeter; but in a platinum tube of the same diameter the depression is 0·655 millimeter. Moreover, the depression depends on the height of the convex meniscus of the mercury, and this height varies for the same tube, according as the meniscus is formed during an ascending or descending motion of the mercurial column in the tube. These results undergo modification if the mercury is impure.

128. **Ascent and depression between parallel or inclined surfa**—When two bodies of any given shape are dipped in water, analog capillary phenomena are produced, provided the bodies are sufficie near. If, for example, two parallel glass plates are immersed in wa

at a very small distance from each other, water will rise between the two plates in the inverse ratio of the distance which separates them. The height of the ascent for any given distance is half what it would be in a tube whose diameter is equal to the distance between the plates.

If the parallel plates are immersed in mercury, a corresponding depression is produced, subject to the same laws.

If two glass plates AB and AC with their planes vertical and inclined to one another at a small angle, as represented in fig. 84, have their ends dipped into a liquid which wets them, the liquid will rise between them. The elevation will be greatest at the line of contact of plates and from thence gradually less, the surface taking the form of an equilateral hyperbola, whose asymptotes are respectively the line of intersection of the plates, and the line in which the plates cut the horizontal surface of the water.

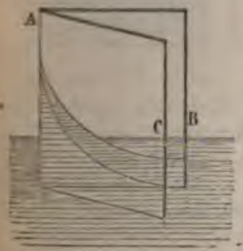


Fig. 84.

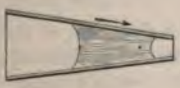


Fig. 85.

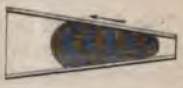


Fig. 86.

If a drop of water be placed within a conical glass tube whose angle is small and axis horizontal it will have a concave meniscus at each end (fig. 85), and will tend to move towards the vertex. But if the drop be of mercury it will have a convex meniscus at each end (fig. 86) and will tend to move from the vertex.

129. **Attraction and repulsion produced by capillarity.**—The attractions and repulsions observed between bodies floating on the surface of liquids are due to capillarity, and are subject to the following laws :—

i. When two floating balls both moistened by the liquid, for example, cork upon water, are so near that the liquid surface between them is not level, an attraction takes place.

ii. The same effect is produced when neither of the balls is moistened, as is the case with balls of wax on water.

iii. Lastly, if one of the balls is moistened and the other not, as a ball of cork and a ball of wax in water, they repel each other if the curved surfaces of the liquid in their respective neighbourhoods intersect.

As all these capillary phenomena depend on the concave or convex curvature which the liquid assumes in contact with the solid, a short explanation of the cause which determines the form of this curvature is ssary.

0. **Cause of the curvature of liquid surfaces in contact with ds.**—The form of the surface of a liquid in contact with a solid

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depends on the relation between the attraction of the solid for the liqui and of the mutual attraction between the molecules of the liquid.

Let *m* be a liquid molecule (fig. 87) in contact with a solid. Th molecule is acted upon by three forces: by gravity, which attracts it the direction of the vertical *m*P; by the attraction of the liquid F, whi acts in the direction *m*F: and by the attraction of the plate *n*, which exerted in the direction *mn*. According to the relative intensities of the forces, their resultant can take three positions:—

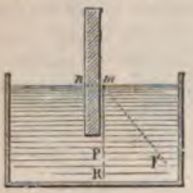

Fig. 87.

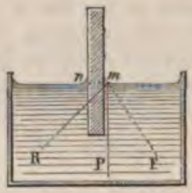

Fig. 88.

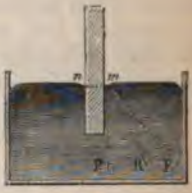

Fig. 89.

i. The resultant is in the direction of the vertical *m*R (fig. 87). In th case the surface *m* is plane and horizontal; for, from the condition of th equilibrium of liquids, the surface must be perpendicular to the for which acts upon the molecules.

ii. If the force *n* increases or F diminishes, the resultant R is withi the angle *nm*P (fig. 88): in this case the surface takes a direction pe pendicular to *m*R, and becomes concave.

iii. If the force F increases, or *n* diminishes, the resultant R takes th direction *m*R (fig. 89) within the angle P*m*F, and the surface becomin perpendicular to this direction is convex.

131. **Influence of the curvature on capillary phenomena.**—T elevation or depression of a liquid in a capillary tube depends on t concavity or convexity of the meniscus. In a concave meniscus, *ab* (fig. 90), the liquid molecules are sustained in equilibrium by the forc acting on them, nd they exercise no downward pressure on the inferi

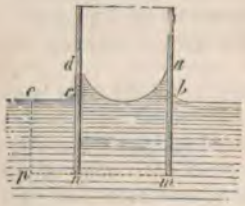

Fig. 90.

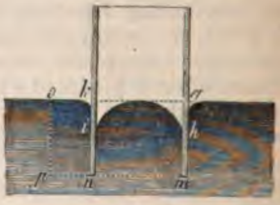

Fig. 91.

layers. On the contrary, in virtue of the molecular attraction, they on the nearest inferior layers, from which it follows that the pressure any layer, *mn*, in the interior of the tube, is less than if there were meniscus. The consequence is, that the liquid ought to rise in the tu until the internal pressure on the layer, *mn*, is equal to the pressure, *op*, which acts externally on a point, *p*, of the same layer.

Where the meniscus is convex (fig. 90) equilibrium exists in virtue of the molecular forces acting on the liquid; but as the molecules which would occupy the space *ghik*, if there were no molecular action, do not exist, they exercise no attraction on the lower layers. Consequently, the pressure on any layer *mn*, in the interior of the tube, is greater than if the space *ghik* were filled, for the molecular forces are more powerful than gravity. The liquid ought, therefore, to sink in the tube until the internal pressure on a layer, *mn*, is equal to the external pressure on any point, *p*, of this layer.

132. **Various capillary phenomena.**—The following facts are among the many which are caused by capillarity :—

When a capillary tube is immersed in a liquid which moistens it, and is then carefully removed, the column of liquid in the tube is seen to be longer than while the tube was immersed in the liquid. This arises from the fact that a drop adheres to the lower extremity of the tube, and forms a concave meniscus, which concurs with that of the upper meniscus to form a longer column (128).

For the same reason a liquid does not overflow in a capillary tube, although the latter may be shorter than the liquid column which would otherwise be formed in it. For when the liquid reaches the top of the tube, its upper surface, though previously concave, becomes convex, and, as the downward pressure becomes greater than if the surface were plane, the ascending motion ceases.

Insects can often move on the surface of water without sinking. This is a capillary phenomenon caused by the fact, that as their feet are not wetted by the water, a depression is produced which keeps them up in spite of their weight. Similarly a sewing needle gently placed on water, does not sink, because its surface, being covered with an oily layer, does not become wetted. But if washed in alcohol, or in potash, it at once sinks to the bottom.

It is from capillarity that sap rises in plants, that oil ascends in the wicks of lamps, that water rises in wood, sponge, bibulous paper, sugar, sand, and in all bodies which possess pores of a perceptible size.

In the next section, under the heads of endosmose, absorption, and imbibition, we shall become acquainted with some new phenomena which greatly resemble capillarity, and are often confounded with it.

ENDOSMOSE, EFFUSION, ABSORPTION, AND IMBIBITION.

133. **Endosmose and exosmose.**—When two different liquids are sepa-
ed by a thin porous partition, either inorganic or organic, a current sets
rom each liquid to the other; to these currents the names *endosmose*
d *exosmose* are respectively given. These terms, which signify *impulse*
m *within* and *impulse from without*, were originally introduced by

M. Dutrochet, who first drew attention to these phenomena. They may be well illustrated by means of the *endosmometer*. This consists of a long tube, at the end of which a membranous bag is firmly bound (fig. 92). The bag is then filled with a strong syrup, or some other solution denser than water, such as milk or albumen, and is immersed in water. The liquid is found gradually to rise in the tube, to a height which may attain several inches : at the same time, the level of the liquid in which the endosmometer is immersed becomes lower. It follows, therefore, that some of the external liquid has passed through the membrane and has mixed with the internal liquid. The external liquid moreover is found to contain some of the internal liquid. Hence two currents have been produced in opposite directions. The flow of the liquid towards that which increases in volume is *endosmose*, and the current in the opposite direction is *exosmose*. If water is placed in the bag, and immersed in syrup, endosmose is produced from the water towards the syrup, and the liquid in the interior diminishes in volume while the level of the exterior is raised.

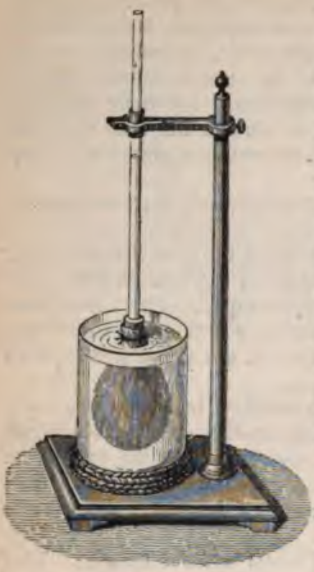

Fig. 92.

The height of the ascent in the endosmometer varies with different liquids. Of all vegetable substances, sugar is that which, for the same density, has the greatest power of endosmose, while albumen has the highest power of all animal substances. In general, it may be said that endosmose takes place towards the denser liquid. Alcohol and ether form an exception to this : they behave like liquids which are denser than water. With acids, according as they are more or less dilute, the endosmose is from the water towards the acid, or from the acid towards water.

According to Dutrochet, it is necessary for the production of endosmose : i. that the liquids be different but capable of mixing, as alcohol and water ; there is no endosmose, for instance, with water and oil ; ii. that the liquids be of different densities ; and iii. that the membrane must be permeable to at least one of the substances.

The current through thin inorganic plates is feeble, but continuous, while organic membranes are rapidly decomposed, and endosmose then ceases.

The well-known fact that dilute alcohol kept in a porous vessel becomes concentrated, depends on endosmose. If a mixture of alcohol and water be kept for some time in a bladder, the volume diminishes, but it becomes much more concentrated. The reason, doubtless, is that the bladder permits the endosmose of water rather than that of alcohol.

Dutrochet's method is not adapted for quantitative measurements, for it does not take into account the hydrostatic pressure produced by the column. Jolly has examined the endosmose of various liquids by weighing the bodies diffused. He calls the *endosmotic equivalent* of a substance the number which expresses how many parts by weight of water pass through the bladder in exchange for one part by weight of the substance. The following are some of the endosmotic equivalents which he determined :—

Chloride of sodium . .	4·3	Caustic potass . . .	215·0
Sulphate of magnesium .	11·7	Sulphuric acid . . .	0·4
" copper. . .	9·5	Alcohol	4·2
Sugar	7·1		

He also found that the endosmotic equivalent increases with the temperature ; and that the quantities of substances which pass in equal times through the bladder are proportional to the strength of the solution.

134. **Diffusion of liquids.**—If oil be poured on water no tendency to intermix is observed, and even if the two liquids be violently agitated together, on allowing them to stand, two separate layers are formed. With alcohol and water the case is different ; if alcohol, which is specifically lighter, be poured upon water, the liquids gradually intermix, they diffuse into one another.

The laws of this diffusion, in which no porous diaphragm intervenes, have been completely investigated by Graham. The method, by which his latest experiments were made, was the following :—In a glass vessel, containing about 700 cubic centimeters of distilled water, about 100 cubic centimeters of the solution to be examined was carefully added by means of a capillary tube, so as to form a layer on the bottom. After a certain interval of time, successive layers were carefully drawn off by a syphon, and their contents examined.

The general results of these investigations may be thus stated :—

i. When solutions of the same substance, but of different strengths, are taken, the quantities diffused in equal times are proportional to the strengths of the solutions.

ii. In the case of solutions containing equal weights of different substances, the quantities diffused vary with the nature of the substances. Saline substances may be divided into a number of *equidiffusive groups*, the rates of diffusion of each group being connected with the others by a simple numerical relation.

iii. The quantity diffused varies with the temperature. Thus taking the rate of diffusion of hydrochloric acid at 15° C. as unity ; at 49° C. it is 18.

iv. If two substances which do not combine be mixed in solution, they may be partially separated by diffusion, the more diffusive one passing out most rapidly. In some cases chemical decomposition even may be

effected by diffusion. Thus bisulphate of potassium is decomposed i
free sulphuric acid and sulphate of potassium.

v. If liquids be dilute a substance will diffuse into water, containing
other substance dissolved as into pure water; but the rate is materia
reduced if a portion of the diffusing substance be already present.

The following table gives the approximate times of equal diffusion :-

Hydrochloric acid	1·0	Sulphate of magnesium .	
Chloride of sodium . .	2·3	Albumen	4
Sugar	7·0	Caramel	9

It will be seen from the above table that the difference between t
rates of diffusion is very great. Thus, sulphate of magnesium, one of t
least diffusible saline substances, diffuses 7 times as rapidly as albume
and 14 times as rapidly as caramel. These last substances, like hydrate
silicic acid, starch, dextrine, gum, etc., constitute a class of substance
which are characterised by their incapacity for taking the crystalline for
and by the mucilaginous character of their hydrates. Considering gela
tine as the type of this class, Graham has proposed to call them *colloi*
(κόλλη, glue), in contradistinction to the far more easily diffusible *crysta
loid* substances.

Graham has proposed a method of separating bodies based on the
unequal diffusibility, which he calls *dialysis.* His *dialyser* consists of
ring of gutta percha over which is stretched while wet a sheet of parc
ment paper, forming thus a vessel about two inches high and ten inch
in diameter, the bottom of which is of parchment paper. After pouri
in the mixed solution to be dialysed, the whole is floated on a ves
containing a very large quantity of water. In the course of one or t
days a more or less complete separation will have been effected. Thus
solution of arsenious acid mixed with various kinds of food readily diffus
out.

The process has received important applications to laboratory a
pharmaceutical purposes.

For further information on this subject the student is referred to a ve
complete article on the diffusion of liquids in the third volume of Wat
Dictionary of Chemistry.

135. **Endosmose of gases.**—The phenomena of endosmose are se
in a high degree in the case of gases. When two different gases are s
parated by a porous diaphragm, an exchange takes place between the
and ultimately the composition of the gas on both sides of the diaphrag
is the same; but the rapidity with which different gases diffuse into ea
other under these circumstances varies considerably. The laws reg
lating this phenomenon have been investigated by Graham. Numero
experiments illustrate it, two of the most interesting of which are the f
lowing :—

A glass cylinder closed at one end is filled with carbonic acid gas,
open end tied over with a bladder, and the whole placed under a jar
hydrogen. Diffusion takes place between them through the porous d

igm, and after the lapse of a certain time hydrogen has passed through bladder into the cylindrical vessel in much greater quantity than the onic acid which has passed out, so that the bladder becomes very

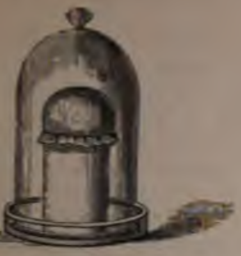

Fig. 93.

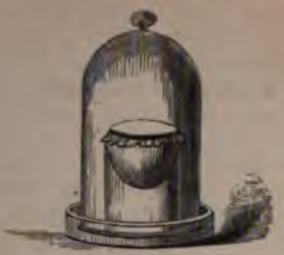

Fig. 94.

h distended outwards (fig. 93). If the cylinder be filled with hydro- and the bell-jar with carbonic acid, the reverse phenomenon will be uced—the bladder will be distended inwards (fig. 94).

tube about 12 inches long, closed at one end by a plug of dry plaster aris, is filled with dry hydrogen, and its open end then immersed in rcury bath. Endosmose of the hydrogen towards the air takes place pidly that a partial vacuum is produced, and mercury rises in the to a height of several inches (fig. 95). If several such tubes are with different gases, and allowed to diffuse into the air in a similar ner, in the same time, different quantities of the various gases will se, and Graham found that the law regulating diffusions is, that *the force of diffusion is in- ly as the square roots of the densities of gases.* , if two vessels of equal capacity, containing en and hydrogen, be separated by a porous , diffusion takes place; and after the lapse of time, for every one part of oxygen which has ed into the hydrogen, four parts of hydrogen passed into the oxygen. Now the density of ogen being 1, that of oxygen is 16, hence the of diffusion is inversely as the square roots of numbers. It is four times as great in the one h has $\frac{1}{16}$th the density of the other.

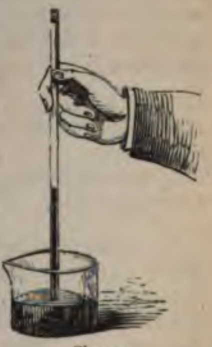

Fig. 95.

6. **Effusion and Transpiration of Gases.**— sion is the term applied to the phenomenon of passage of gases into vacuum, through a minute aperture not much or less than 0·013 millimeter in diameter, in a thin plate of metal glass. Within the limits of experimental errors, the rates of effusion ferent gases coincide with those of their diffusion.

however, the gases issue through long, fine capillary tubes into a um, the rate of efflux, or the *velocity of transpiration*, is independent e rate of diffusion.

i. *For the same gas, the rate of transpiration increases, other things being equal, directly as the pressure*; that is, equal volumes of air of different densities require times inversely proportional to their densities.

ii. *With tubes of equal diameters, the volume transpired in equal times is inversely as the length of the tube.*

iii. *As the temperature rises the transpiration becomes slower.*

iv. *The rate of transpiration is independent of the material of the tube.*

137. **Absorption and imbibition.**—The words absorption and imbibition are used almost promiscuously in physics; they indicate the penetration of a liquid or a gas into a porous body. Absorption is used both for liquids and gases, while imbibition is restricted to liquids.

In physiology an important distinction is made between the two words; absorption means the penetration of a foreign substance into the tissues of a living body, while imbibition refers to penetration into bodies deprived of life, whether organic or not.

138. **Absorption of gases.**—The surfaces of all solid bodies exert an attraction on the molecules of gases with which they are in contact, of such a nature, that they become covered with a more or less thick layer of *condensed gas.* When a porous body, which consequently presents an immensely increased surface in proportion to its size, is placed in a gas over mercury, the great diminution of volume which ensues indicates that considerable quantities of gas are absorbed.

Now, although there is no absorption such as arises from chemical combinations between the solid and gas (as with phosphorus and oxygen), still the quantity of gas absorbed is not entirely dependent on the physical conditions of the solid body; it is influenced in some measure by the chemical nature both of the solid and the gas. Of all bodies box-wood charcoal has the greatest absorptive power. One volume of this substance at the ordinary temperature and pressure absorbs the following quantities of gas :—

Ammonia . . .	90 vol.	Carbonic oxide . .	9·4 vol.
Hydrochloric acid . .	85 „	Oxygen	9·2 „
Sulphurous „ . .	65 „	Nitrogen	7·5 „
Sulphuretted hydrogen .	55 „	Hydrogen . . .	1·75 „
Carbonic acid . . .	35 „		

The absorptive power of pine charcoal is half as much as that of box-wood. The charcoal made from corkwood, which is very porous, is not absorbent; neither is graphite. Platinum, in the finely divided form known as platinum sponge, is said to absorb 250 times its volume of oxygen gas. Many other porous substances, such as meerschaum, gypsum, silk, etc., are also highly absorbent.

139. **Absorption in plants.**—Absorption takes place in all parts of the plant, but more especially in the rootlets and by the leaves. These organs absorb, in the form of water, carbonic acid, and ammonia, the oxygen, hydrogen, carbon, and nitrogen necessary for the growth of the plants.

Liquids, and the salts which they hold in solution, are absorbed by the

by a double process of capillarity and endosmose. The sap,
then elaborated by the plant, increasing in density towards the
art, owes its ascending direction to endosmose. The ascent of
s also promoted by the vacuum which the exhalations through
s tend to produce. Capillary action can only raise the liquid in
cells ; it cannot produce a current.

bsorption in animals.—In the lower animals whose tissues are
nly of cellules, nutrition is accomplished as in plants by absorp-
endosmose. The absorption by which some of these animals
shed is in reality endosmose.

higher animals also absorption is met with. Madder admin-
an animal penetrates its bones and colours them red. If a
in contact with a cutaneous surface from which the epidermis
removed, or with a mucous membrane, both which are very
the liquid passes into the vessels by endosmose; this constitutes
n.

ore liquid a substance, the more readily is it absorbed. At the
e a liquid must moisten a membrane in order to be absorbed.
stances, which do not moisten surfaces, are not absorbed. But
rd has found that when they are made into an emulsion with
c juice, absorption readily takes place. And Dr. Loze has
bserved that cod-liver oil, when made into an emulsion, has a
rgetic action, which doubtless arises from its being more com-
sorbed.

dosmose, absorption is promoted by heat, and also by depletion.
ious perspiration or loss of blood it also increases.

BOOK IV.

ON GASES.

CHAPTER I.

PROPERTIES OF GASES. ATMOSPHERE. BAROMETERS.

141. **Physical properties of gases.**—Gases are bodies whose molecules are in a constant state of repulsion, in virtue of which they possess the most perfect mobility, and are continually tending to occupy a greater space. This property of gases is known by the names *expansibility*, *tension*, or *elastic force*, from which they are often called *elastic fluids*.

Gases and liquids have several properties in common, and some in which they seem to differ are in reality only different degrees of the same property. Thus, in both, the particles are capable of moving; in gases quite freely; in liquids not quite freely, owing to a certain degree of viscosity. Both are compressible, though in very different degrees; if a liquid and a gas both exist under the pressure of one atmosphere, and then the pressure be doubled, the water is compressed by about the $\frac{1}{200000}$th part, while the gas is compressed by one-half. In density there is a great difference: water, which is the type of liquids, is 770 times as heavy as air, the type of gaseous bodies, while under a pressure of one atmosphere. The property by which gases are distinguished from liquids is their tendency to indefinite expansion.

Matter assumes the solid, liquid, or gaseous form according to the relative strength of the cohesive and repulsive forces exerted between their particles. In liquids these forces balance; in gases repulsion preponderates.

By the aid of pressure and of very low temperatures, the force of cohesion may be so far increased in many gases that they are converted into liquids, and there is every reason for believing that with sufficient pressure and cold they might all be liquefied. On the other hand, heat, which increases the force of repulsion, converts liquids, such as water, alcohol, and ether, into the aëriform state in which they obey all the laws of gases. This aëriform state of liquids is known by the name of *vapour*, while gases are bodies which, under ordinary temperature and pressure, remain in the aëriform state.

In describing the properties of gases we shall, for obvious reasons, have exclusive reference to atmospheric air as their type.

Expansibility of gases.—This property of gases, their tendency ume continually a greater volume, is exhibited by means of the ng experiment. A bladder closed by a stopcock and about half air is placed under the receiver of the air pump (fig. 96), and a n is produced, on which the bladder iately distends. This arises from t that the molecules of air repel her and press against the sides of idder. Under ordinary conditions ternal pressure is counterbalanced air in the receiver, which exerts an and contrary pressure. But when essure is removed by exhausting eiver, the internal pressure becomes . When air is admitted into the r the bladder resumes its original

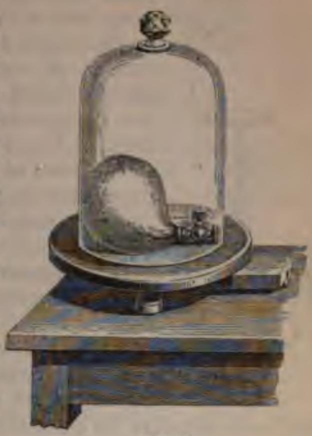
Fig 96.

Compressibility of gases.—The ssibility of gases is readily shown *pneumatic* syringe (fig. 97). This s of a stout glass tube closed at d, and provided with a tight-fitting piston. When the rod of the is pressed, it moves down in the tube, and the air becomes ssed into a smaller volume; but, as soon as the force is removed

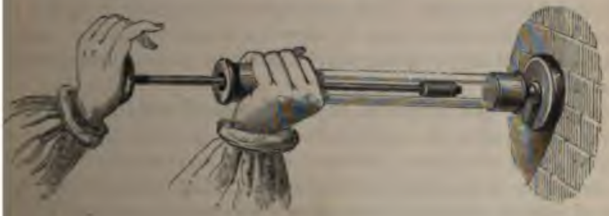
Fig. 97.

r regains its original volume, and the piston rises to its former n.

Weight of gases.—From their extreme fluidity and expansi- gases seem to be uninfluenced by the force of gravity; they heless possess weight, like solids and liquids. To show this, a glass of 3 or 4 quarts capacity is taken (fig. 98), the neck of which is ed with a stopcock, which hermetically closes it, and by which it e screwed to the plate of the air pump. The globe is then ex- d, and its weight determined by means of a delicate balance. Air allowed to enter, and the globe again weighed. The weight in cond case will be found to be greater than before, and if the capacity of the vessel is known, the increase will obviously be the weig of that volume of air.

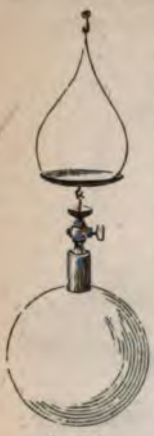

Fig. 98.

By a modification of this method, and with the ado tion of certain precautions, the weight of air and of oth gases has been determined : 100 cubic inches of dry a under the ordinary atmospheric pressure of 30 in. an at the temperature of 16° C., weigh 31 grains ; the sam volume of carbonic acid gas under the same circum stances weigh 47·25 grains; 100 cubic inches of hydr gen the lightest of all gases, weigh 2·14 grains; and 10 cubic inches of hydriodic acid gas weigh 146 grains.

The ratio of the density of air at 0° C. and 30 inche pressure to that of water at 0° C. is found to be 0·00129 In other words, the latter is 771 times as heavy as th former.

145. **Pressures exerted by gases.**—Gases exert o their own molecules, and on the sides of vessels whic contain them, pressures which may be regarded fro two points of view: First, we may neglect the weight o the gas; secondly, we may take account of its weigh If we neglect the weight of any gaseous mass at res and only consider its expansive force, it will be seen that the pressure due to this force act with the same intensity on all points, both of th mass itself and of the vessel in which it is contained. For it is a neces sary consequence of the elasticity and perfect fluidity of gases, that th repulsive force between the molecules is the same at all points, and act equally in all directions. This principle of the equality of the pressur of gases in all directions may be shown experimentally by means of a apparatus resembling that by which the same principle is demonstrate for liquids (fig. 51).

If we consider the weight of any gas we shall see that it gives rise t pressures which obey the same laws as those produced by the weight o liquids. Let us imagine a cylinder, with its axis vertical, several mile high, closed at both ends and full of air. Let us consider any smal portion of the air enclosed between two horizontal planes. This portio must sustain the weight of all the air above it, and transmit that weigh to the air beneath it, and likewise to the curved surface of the cylinde which contains it; and at each point in a direction at right angles to th surface. Thus the pressure increases from the top of the column to th base ; at any given layer, it acts equally on equal surfaces, and at righ angles to them, whether they are horizontal, vertical, or inclined. Th pressure acts on the sides of the vessel, and on any small surface it i equal to the weight of a column of gas, whose base is this surface, an whose height its distance from the summit of the column. The pressur is also independent of the shape and dimensions of the supposed cylinde provided the height remains the same.

For a small quantity of gas the pressures due to its weight are qui insignificant, and may be neglected; but for large quantities, like th atmosphere, the pressures are considerable, and must be allowed for.

146. **The atmosphere. Its composition.**—The atmosphere is the layer of air which surrounds our globe in every part. It partakes of the rotatory motion of the globe, and would remain fixed relatively to terrestrial objects, but for local circumstances, which produce winds, and are constantly disturbing its equilibrium.

Air was regarded by the ancients as one of the four elements. Modern chemistry, however, has shown that it is a mixture of oxygen and nitrogen gases in the proportion of 20·8 volumes of the former to 79·2 volumes of the latter. By weight it consists of 23 parts of oxygen to 77 parts of nitrogen.

The atmosphere also contains a quantity of aqueous vapour, which varies with the temperature, the season, the locality, and the direction of the winds. It further contains a small quantity of ammoniacal gas, and from 3 to 6 parts in 10,000 of its volume of carbonic acid.

The carbonic acid arises from the respiration of animals, from the processes of combustion, and from the decomposition of organic substances. M. Boussingault has estimated that in Paris the following quantities of carbonic acid are produced every 24 hours :—

By the population and by animals .	11,895,000	cubic feet
By processes of combustion . . .	92,101,000	„
	103,996,000	„

Notwithstanding this enormous continual production of carbonic acid on the surface of the globe, the composition of the atmosphere does not vary; for plants in the process of vegetation decompose the carbonic acid, assimilating the carbon, and restoring to the atmosphere the oxygen which is being continually consumed in the processes of respiration and combustion.

147. **Atmospheric pressure.**—If we neglect the perturbations to which the atmosphere is subject, as being inconsiderable, we may consider it as a fluid sea of a certain depth, surrounding the earth on all sides, and exercising the same pressure as if it were a liquid of very small density. Consequently, the pressure on the unit of area is constant at a given level, being equal to the weight of the column of atmosphere above that level whose horizontal section is the unit of area. It will act at right angles to the surface, whatever be its position. It will diminish as we ascend, and increase as we descend from that level. Consequently, at the same height, the atmospheric pressures on unequal plane surfaces will be proportional to the areas of those surfaces, provided they be small in proportion to the height of the atmosphere.

In virtue of the expansive force of the air, it might be supposed that the molecules would expand indefinitely into the planetary spaces. But, in proportion as the air expands, its expansive force decreases, and is further weakened by the low temperature of the upper regions of the atmosphere, so that, at a certain height, an equilibrium is established between the expansive force which separates the molecules, and the action of gravity which draws them towards the centre of the earth. It is therefore concluded that the atmosphere is limited.

From the weight of the atmosphere, and its decrease in density, and from the observation of certain phenomena of twilight, its height has been estimated at from 30 to 40 miles. Above that height the air is extremely rarefied, and at a height of 60 miles it is assumed that there is a perfect vacuum. From certain observations made in the tropical zone, and particularly at Rio Janeiro, on the twilight arc, M. Liais estimates the height of the atmosphere at between 198 and 212 miles, considerably higher, therefore, than what has hitherto been believed.

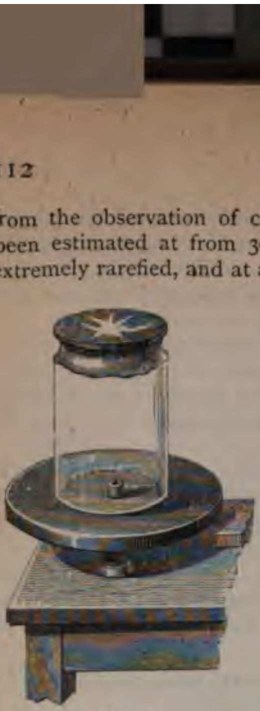
Fig. 99.

As it has been previously stated that 100 cubic inches of air weigh 31 grains, it will readily be conceived that the whole atmosphere exercises a considerable pressure on the surface of the earth. The existence of this pressure is shown by the following experiments.

148. **Crushing force of the atmosphere.**—On one end of a stout glass cylinder, about 5 inches high, and open at both ends, a piece of bladder is tied quite air-tight. The other end, the edge of which is ground and well greased, is pressed on the plate of the air pump (fig. 99). As soon as a vacuum is produced in the vessel, by working the air pump, the bladder is depressed by the weight of the atmosphere above it, and finally bursts with a loud report caused by the sudden entrance of the air.

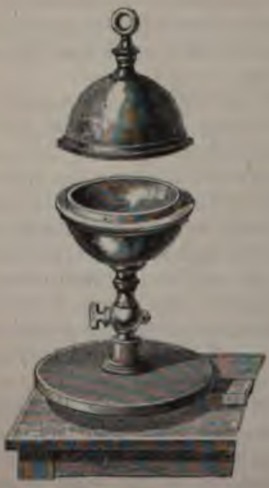
Fig. 100.

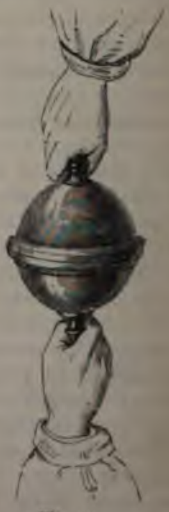
Fig. 101.

agdeburg hemispheres.—The preceding experiment only illustrate the downward pressure of the atmosphere. By means *gdeburg hemispheres* (figs. 100 and 101), the invention of which is to von Guericke, burgomaster of Magdeburg, it can be shown ressure acts in all directions. This apparatus consists of two ss hemispheres of 4 to 4½ inches diameter, the edges of which to fit tightly, and are well greased. One of the hemispheres is with a stopcock, by which it can be screwed on the air pump, e other there is a handle. As long as the hemispheres contain an be separated without any difficulty, for the external pressure mosphere is counterbalanced by the elastic force of the air in or. But when the air in the interior is pumped out by means pump, the hemispheres cannot be separated without a power- ; and as this is the case in whatever position they are held, it at the atmospheric pressure is transmitted in all directions.

INATION OF THE ATMOSPHERIC PRESSURE. BAROMETERS.

rricelli's experiment.—The above experiments demonstrate the of the atmospheric pressure, but they give no precise indications mount. The following experi- ich was first made, in 1643, celli, a pupil of Galileo, gives measure of the weight of phere.

s tube is taken, about a yard a quarter of an inch internal (fig. 102). It is sealed at one is quite filled with mercury. ture C being closed by the he tube is inverted, the open d in a small mercury trough, thumb removed. The tube vertical position, the column y sinks, and, after oscillating e, it finally comes to rest at a , which at the level of the out 30 inches above the mer- he trough. The mercury is the tube by the pressure of sphere on the mercury in gh. There is no contrary on the mercury in the tube, it is closed. But if the end be be opened, the atmosphere s equally inside and outside and the mercury will sink to of that in the trough. It shown in hydrostatics (102) that the heights of two columns of

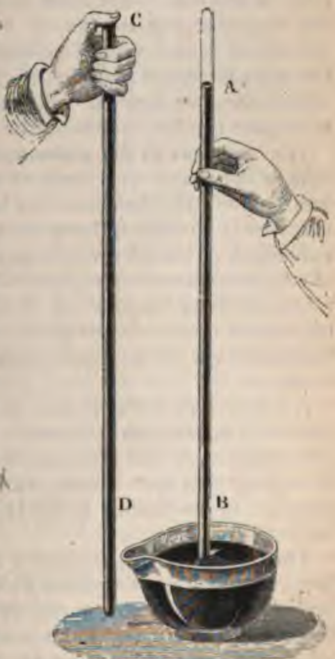

Fig. 102.

liquid in communication with each other are inversely as their densities, and hence it follows, that the pressure of the atmosphere is equal to that of a column of mercury, the height of which is 30 inches. If, however, the weight of the atmosphere diminishes, the height of the column which it can sustain must also diminish.

151. **Pascal's experiments.**—Pascal, who wished to prove that the force which sustained the mercury in the tube was really the pressure of the atmosphere, made the following experiments. i. If it were the case, the column of mercury ought to descend in proportion as we ascend in the atmosphere. He accordingly requested one of his relations to repeat Torricelli's experiment on the summit of the Puy de Dôme in Auvergne. This was done, and it was found that the mercurial column was about 3 inches lower, thus proving that it is really the weight of the atmosphere which supports the mercury, since, when this weight diminishes, the height of the column also diminishes. ii. Pascal repeated Torricelli's experiment at Rouen, in 1646, with other liquids. He took a tube closed at one end, nearly 50 feet long, and having filled it with water, placed it vertically in a vessel of water, and found that the water stood in the tube at a height of 34 feet; that is, 13·6 times as high as mercury. But since mercury is 13·6 times as heavy as water, the weight of the column of water was exactly equal to that of the column of mercury in Torricelli's experiment, and it was consequently the same force, the pressure of the atmosphere, which successively supported the two liquids. Pascal's other experiments with oil and with wine gave similar results.

152. **Amount of the atmospheric pressure.**—Let us assume that the tube in the above experiment is a cylinder, the section of which is equal to a square inch, then since the height of the mercurial column in round numbers is 30 inches, the column will contain 30 cubic inches, and as a cubic inch of mercury weighs 3433·5 grains = 0·49 of a pound, the pressure of such a column on a square inch of surface is equal to 14·7 pounds. In round numbers the pressure of the atmosphere is taken at 15 pounds on the square inch. A surface of a foot square contains 144 square inches, and therefore the pressure upon it is equal to 2,160 pounds, or nearly a ton.

A gas or liquid which acts in such a manner that a square inch of surface is exposed to a pressure, 15 pounds, is called a pressure of *one atmosphere*. If, for instance, the elastic force of the steam of a boiler is so great that each square inch of the internal surface is exposed to a pressure of 90 pounds (= 6 × 15), we say it is under a pressure of six atmospheres.

The surface of the body of a man of middle size is about 16 square feet; the pressure, therefore, which a man supports on the surface of his body is 35,560 pounds, or nearly 16 tons. Such an enormous pressure might seem impossible to be borne; but it must be remembered that in all directions there are equal and contrary pressures which counterbalance one another. It might also be supposed that the effect of this force, acting in all directions, would be to press the body together and crush it. But the solid parts of the skeleton could resist a far greater pressure; and as to the air and liquids contained in the organs and vessels, the air has the same density as the external air, and cannot be further compressed by the atmospheric pressure; and from what has been said about liquids (92) it is clear that they are virtually incompressible. When the external pressure is removed from any part of the body, either by means of a cupping vessel or by the air pump, the pressure from within is seen by the distension of the surface.

153. **Different kinds of barometers.**—The instruments used for measuring the atmospheric pressure are called *barometers*. In ordinary barometers, the pressure is measured by the height of a column of mercury, as in Torricelli's experiment: the barometers which we are about to describe are of this kind. But there are barometers without any liquid, one of which, the aneroid, is remarkable for its simplicity and portability.

154. **Cistern barometer.**—The *cistern barometer* consists of a straight glass tube closed at one end, about 33 inches long, filled with mercury, and dipping into a cistern containing the same metal. In order to render the barometer more portable, and the variations of the level in the cistern less perceptible when the mercury rises or falls in the tube, several different forms have been constructed. Fig. 103 represents one form of the cistern barometer. The apparatus is fixed to a mahogany stand, on the upper part of which there is a scale graduated in millimeters or inches from the level of the mercury in the cistern; a moveable index, *i*, shows on the scale the level of the mercury. A thermometer on one side of the tube indicates the temperature.

There is one fault to which this barometer is liable, in common with all others of the same kind. The zero of the scale does not always correspond to the level of the mercury in the cistern. For as the atmospheric pressure is not always the same, the height of the mercurial column varies: sometimes mercury is forced from the cistern into the tube, and sometimes from the tube into the cistern, so that, in the majority of cases, the graduation of the barometer does not indicate the true height. If the diameter of the cistern is large, relatively to that of the tube, the error from this source is lessened. The *height* of the barometer is the distance between the levels of the mercury in the tube and in the cistern. Hence the barometer should always be perfectly vertical; for, if not, the tube being inclined, the column of mercury is elongated (fig. 104), and the number read off on the scale is too great. As the pressure which the mercury exerts by its weight at the base of the tube is independent of the form of the tube and of its diameter (102), provided it is not capillary, the height of the barometer is independent of the diameter of the tube and of its shape, but is inversely as the density of the liquid. With mercury the mean height at the level of the sea is 29·92, or in round numbers 30, inches; in a water barometer it would be about 33·7 feet.

155. **Fortin's barometer.**—*Fortin's barometer* differs from that just described, in the shape of the cistern. The base of the cistern is made of

leather, and can be raised or lowered by means of a screw; this has th advantage, that a constant level can be obtained, and also that the ir strument is made more portable. For, in travelling, it is only necessar to raise the leather until the mercury, which rises with it, quite fills th cistern; the barometer may then be inclined, and even inverted withou any fear that a bubble of air may enter, or that the shock of the mercur may crack the tube.

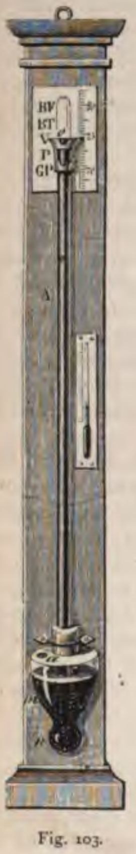

Fig. 103.

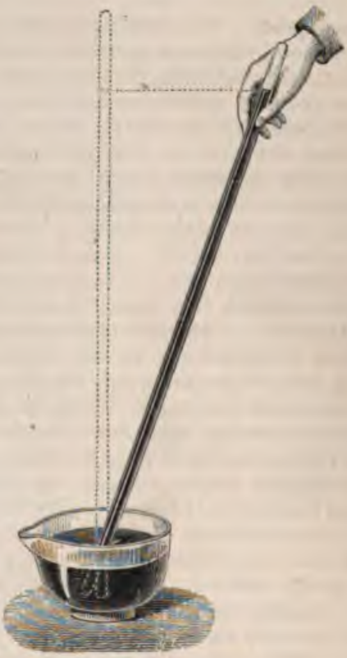

Fig. 104.

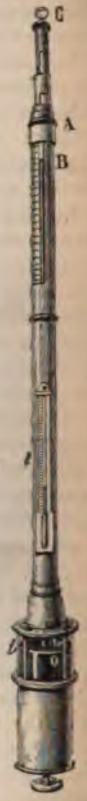

Fig. 105.

Fig. 105 represents the arrangement of the barometer, the tube of whi is placed in a brass case. At the top of this case, there are two longitud nal apertures, on opposite sides, so that the level of the mercury, B, seen. The scale on the case is graduated in millimeters. An index moved by the hand, gives, by means of a vernier, the height of the me cury to $\frac{1}{10}$th of a millimeter. At the bottom of the case there is the cistern *h*, containing mercury, O.

Fig. 106 shows the details of the cistern on a larger scale. It consists of a glass cylinder *b*, through which the mercury can be seen; this is closed at the top by a box-wood disc fitted on the under-surface of the brass cover M. Through this passes the barometer tube E, which is drawn out at the end, and dips in the mercury; the cistern and the tube are connected by a piece of buckskin *ce*, which is firmly tied at *c* to a contraction in the tube, and at *e* to a brass tubulure in the cover of the cistern. This mode of closing prevents the mercury from escaping when

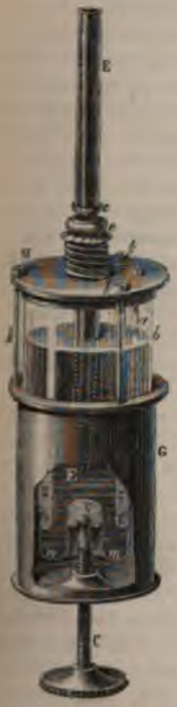

Fig. 106.

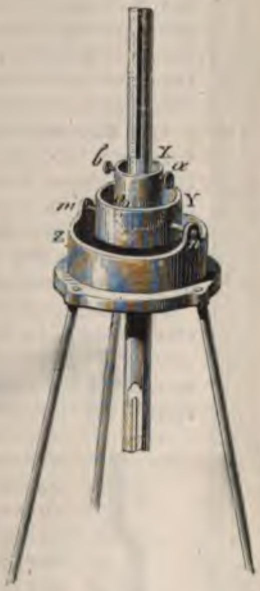

Fig. 107.

the barometer is inverted, while the pores of the leather transmit the atmospheric pressure. The bottom of the cylinder *b* is cemented on a box-wood cylinder *zz*, on a contraction in which, *ii*, is firmly tied the buckskin *mn*, which forms the base of the cistern. On this skin is fastened a wooden button *x*, which rests against the end of a screw C. According as this is turned in one direction or the other, the skin *mn* is raised or lowered; and with it the mercury. In using this barometer the mercury is first made exactly level with the point *a*, which is effected by turning th screw C either in one direction or the other. The graduation of the scal is counted from this point *a*, and thus the distance of the top B of th column of mercury from *a* gives the height of the barometer. The bottor of the cistern is surrounded by a brass case, which is fastened to the cove M by screws, *k*, *k*, *k*. We have already seen (154) the importance having the barometer quite vertical, which is effected by the followin means, known as *Cardan's suspension.*

The metal case containing the barometer is fixed in a copper sheath by two screws *a* and *b* (fig 107). This is provided with two axles (onl one of which, *o*, is seen in the figure), which turn freely in two holes in ring Y. In a direction at right angles to that of the axles, *o* the ring has also two similar axles, *m* and *n*, resting on a sup port Z. By means of this double suspension, the baromete can oscillate freely about the axis, *mn* and *oo*, in two direction at right angles to each other. But as care is taken that th point at which these cross corresponds to the tube itself, th centre of gravity of the system, which must always be lowe than the axis of suspension, is below the point of intersec tion, and the barometer is then perfectly vertical.

156. **Gay-Lussac's syphon barometer.**—The sypho barometer is a bent glass tube, one of the branches of whic is much longer than the other. The longer branch, whic is closed at the top, is filled with mercury as in the cister barometer, while the shorter branch, which is open, serve as a cistern. The difference between the two levels is th height of the barometer.

Fig. 108 represents the syphon barometer as modified by Gay-Lussac. In order to render it more available for travelling by preventing the entrance of air, he joined the two branches by a capillary tube: when the instrument is inverted, the tube always remains full in virtue of its capillarity, and air cannot penetrate into the longer branch. A sudden shock, however, might separate the mercury and admit some air. To avoid this, M. Bunten has introduced an ingenious modification into the apparatus. The longer branch is drawn out to a fine point, and is joined to a tube K, of the form represented in fig. 109. By this arrangement, if air passes through the capillary tube it cannot penetrate the drawn out extremity of the longer branch, but lodges in the upper part of the enlargement K. In this position it does not affect the observations, since the vacuum is always at the upper part of the tube; it is moreover easily removed.

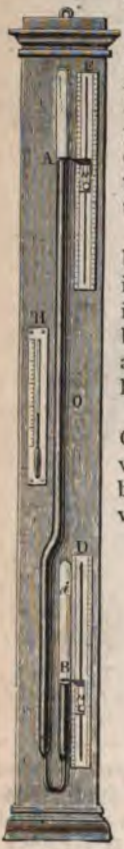

Fig. 108.

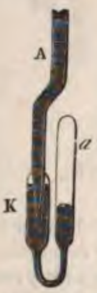

Fig. 109.

In Gay-Lussac's barometer the shorter branch is closed, but there is a lateral capillary aperture *a*, through which the atmospheric pressure is transmitted.

The barometric height is determined by means of two scales, which have a common zero at O, towards the middle of the longer branch, and are graduated in contrary directions, the one from O to E, and the other from O to B, either on the tube itself, or on brass rules fixed parallel to the tube. Two sliding verniers, *m* and *n*, indicate $\frac{1}{10}$th of a millimeter. The total height of the barometer, AB, is the sum of the distances from O to A and from O to B.

157. **Precautions in reference to barometers.**—In constructing barometers, mercury is chosen in preference to any other liquid. For being the densest of all liquids, it stands at the least height. When the mercurial barometer stands at 30 inches, the water barometer would stand at about 34 feet. It also deserves preference because it does not moisten the glass. It is necessary that the mercury be pure and free from oxide; otherwise it adheres to the glass and tarnishes it. Moreover, if it is impure its density is changed, and the height of the barometer is too great or too small. Mercury is purified, before being used for barometers, by treatment with dilute nitric acid, and by distillation.

The space at the top of the tube (figs. 102 and 103), which is called the *Torricellian vacuum*, must be quite free from air and from aqueous vapour, for otherwise either would depress the mercurial column by its elastic force. To obtain this result, a small quantity of pure mercury is placed in the tube and boiled for some time. It is then allowed to cool, and a further quantity, previously warmed, added, which is boiled, and so on, until the tube is quite full; in this manner the moisture and the air which adhere to the sides of the tube pass off with the mercurial vapour.

A barometer is free from air and moisture if, when it is inclined, the mercury strikes with a sharp metallic sound against the top of the tube. If there is air or moisture in it, the sound is deadened.

158. **Correction for capillarity.**—In cistern barometers there is always a certain depression of the mercurial column due to capillarity, unless the internal diameter of the tube exceeds 0·8 inch. To make the correction due to this depression, it is not enough to know the diameter of the tube, we must also know the height of the meniscus *od* (fig. 110), which varies according as the meniscus has been formed during an ascending or descending motion of the mercury in the tube. Consequently, the height of the meniscus must be determined by bringing the pointer to the level *ab*, and then to the level *d*, when the difference of the readings will give the height *od* required. These two terms, namely, the internal diameter of the tube and the height of the meniscus, being known, the resulting correction can be taken out of the following table, which follows the arrangement usually adopted for a multiplication table:—

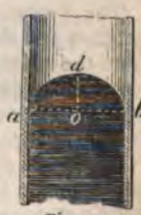

Fig. 110.

Internal Diameter in inches	Height of Sagitta of Meniscus in inches						
	0·010	0·015	0·020	0·025	0·030	0·035	0·040
0·157	0·0293	0·0431	0·0555	0·0677	0·0780	0·0870	0·0948
0·236	0·0119	0·0176	0·0231	0·0294	0·0342	0·0398	0·0432
0·315	0·0060	0·0088	0·0118	0·0144	0·0175	0·0196	0·0221
0·394	0·0039	0·0048	0·0063	0·0078	0·0095	0·0110	0·0125
0·472	0·0020	0·0029	0·0036	0·0045	0·0053	0·0063	0·0073
0·550	0·0010	0·0017	0·0024	0·0029	0·0034	0·0039	0·0044

In Gay-Lussac's barometer the two tubes are made of the same di meter, so that the error caused by the depression in the one tube ver nearly corrects that caused by the depression in the other. As, howeve the meniscus in the one tube is formed by a column of mercury with a ascending motion, while that in the other by a column with a descendin motion, their heights will not be the same, and the reciprocal correctio will not be quite exact.

159. **Correction for temperature.**—In all observations with bar meters, whatever be their construction, a correction must be made f temperature. Mercury contracts and expands with different temper tures; hence its density changes, and consequently the barometr height, for this height is in the inverse ratio of the density of th mercury; so that for different atmospheric pressures the mercur column might have the same height. Accordingly, in each observatio the height observed must be reduced to a determinate temperature; th choice of this is quite arbitrary, but that of melting ice is always adopte It will be seen, in the Book on Heat, how this correction is made.

By the aid of tables which have been prepared for this purpose, th height of the barometer is readily reduced to zero Centigrade.

160. **Variations in the height of the barometer.**—When the bar meter is observed for several days, its height is found to vary in the sa place, not only from one day to another, but also during the same day.

The extent of these variations, that is, the difference between th greatest and the least height, is different in different places. It increas from the equator towards the poles. Except under extraordinary circu stances, the greatest variations do not exceed six millimeters under th equator, 30 under the tropic of Cancer, 40 in France, and 60 at 25 degre from the pole. The greatest variations are observed in winter.

The *mean daily height* is the height obtained by dividing the sum 24 successive hourly observations by 24. In our latitudes, the baromet height at noon corresponds to the mean daily height.

The *mean monthly height* is obtained by adding together the me daily heights for a month, and dividing by 30.

The *mean yearly height* is similarly obtained.

Under the equator, the mean annual height at the level of the sea

^{m}·758, or 29·84 inches. It increases from the equator, and between the latitudes 30° and 40° it attains a maximum of 0^{m}·763, or 30·04 inches. In lower latitudes it decreases, and in Paris it does not exceed 0^{m}·7568.

The general mean at the level of the sea is 0^{m}·761, or 29·96 inches.

The mean monthly height is greater in winter than in summer, in consequence of the cooler atmosphere.

Two kinds of variations are observed in the barometer :—1st, the *accidental variations*, which present no regularity; they depend on the seasons, the direction of the winds, and the geographical position, and are common in our climates : 2nd, the *daily variations*, which are produced periodically at certain hours of the day.

At the equator, and between the tropics, no accidental variations are observed ; but the daily variations take place with such regularity that a barometer may serve to a certain extent as a clock. The barometer sinks from midday till towards four o'clock ; it then rises, and reaches its maximum at about ten o'clock in the evening. It then again sinks, and reaches a second minimum towards four o'clock in the morning, and a second maximum at ten o'clock.

In the temperate zones there are also daily variations, but they are detected with difficulty, since they occur in conjunction with accidental variations.

The hours of the maxima and minima appear to be the same in all climates, whatever be the lattitude ; they merely vary a little with the seasons.

161. **Causes of barometric variations.**— It is observed that the course of the barometer is generally in the opposite direction to that of the thermometer ; that is, that when the temperature rises the barometer falls, and *vice versâ* ; which indicates that the barometric variations at any given place are produced by the expansion or contraction of the air, and therefore by its change in density. If the temperature were the same throughout the whole extent of the atmosphere, no currents would be produced, and, at the same height, the atmospheric pressure would be everywhere the same. But when any portion of the atmosphere becomes warmer than the neighbouring parts, its specific gravity is diminished, and it rises and passes away through the upper regions of the atmosphere, whence it follows that the pressure is diminished, and the barometer falls. If any portion of the atmosphere retains its temperature, while the neighbouring parts become cooler, the same effect is produced ; for in this case, too, the density of the first-mentioned portion is less than that of the others. Hence, also, it usually happens that an extraordinary fall of the barometer at one place is counterbalanced by an extraordinary rise at another place. The daily variations appear to result from the expansions and contractions which are periodically produced in the atmosphere by the heat of the sun during the rotation of the earth.

2. **Relation of barometric variations to the state of the weather.** has been observed that, in our climate, the barometer in fine weather nerally above 30 inches, and is below this point when there is rain, , wind, or storm, and also, that for any given number of days at

which the barometer stands at 30 inches, there are as many
rainy days. From this coincidence between the height of the ba
and the state of the weather, the following indications hav
marked on the barometer, counting by thirds of an inch above an
30 inches :

Height	State of the weather
31 inches	Very dry.
30$\frac{2}{3}$ „	Settled weather.
30$\frac{1}{3}$ „	Fine weather.
30 „	Variable.
29$\frac{2}{3}$ „	Rain or wind.
29$\frac{1}{3}$ „	Much rain.
29 „	Tempest.

In using the barometer as an indicator of the state of the weat
must not forget that it really only serves to measure the weight
atmosphere, and that it only rises
as this weight increases or dimi
and although a change of weath
quently coincides with a change
pressure, they are not necessari
nected. This coincidence arise
meteorological conditions peculiar
climate, and does not always occu
a fall in the barometer usually p
rain in our latitudes, is caused
position of Europe. The south-wes
which are hot and consequentl
make the barometer sink; but
same time, as they become charg
aqueous vapour in crossing the
they bring us rain. The winds
north and north-east, on the c
being colder and denser, make th
meter rise; and as they only re
after having passed over vast co
they are generally dry.

When the barometer rises o
slowly, that is, for two or thre
towards fine weather or towards
has been found from a great nu
observations that the indications a
extremely probable. Sudden va
in either direction indicate bad
or wind.

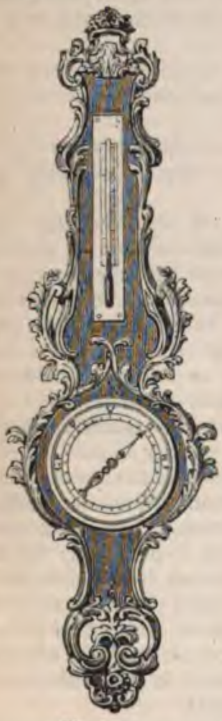

Fig. 111.

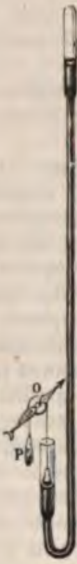

Fig. 112.

163. **Wheel barometer.**—Th
barometer, which was invented by Hooke, is a syphon baromete
especially intended to indicate good and bad weather (fig. 111).
shorter leg of the syphon there is a float, which rises and falls

ury (fig. 112). A string attached to this float passes round a pulley, d at the other end there is a weight, P, somewhat lighter than the A needle fixed to the pulley moves round a graduated circle, on is marked, *variable*, *rain*, *fine weather*, etc. When the pressure the float sinks or rises, and moves the needle round to the corre- ling points on the scale.

barometers ordinarily met with in houses, and which are called *r glasses*, are of this kind. They are, however, of little use, for two s. The first is, that they are neither very delicate nor precise in ndications. The second, which applies equally to all barometers, those commonly in use in this country are made in London, and dications, if they are of any value, are only a place of the same level and of the same c conditions as London. Thus a barometer g at a certain height in London would in- certain state of weather, but if removed to 's Hill it would stand half an inch lower, uld indicate a different state of weather. pressure differs with the level and with hical conditions, it is necessary to take to account if exact data are wanted.

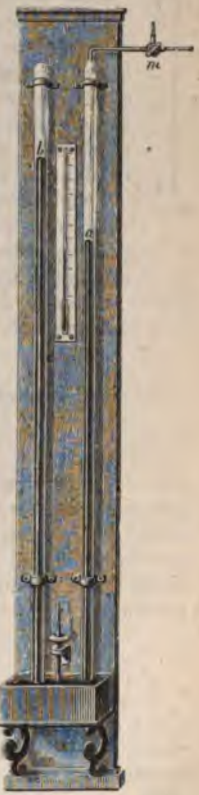

Fig. 113.

ixed barometer.—For accurate observa- egnault uses a barometer the height of e measures by means of a cathetometer (83). tern (fig. 113) is of cast iron; against the n which it is supported a screw is fitted, s pointed at both ends, and the length of as been determined, once for all, by the neter. To measure the barometric height w is turned until its point grazes the surface ercury in the bath, which is the case when nt and its image are in contact. The then from the top of the point to the level nercury in the tube *b* is measured by the neter, and this together with the length of w gives the barometric height with great y. This barometer has moreover the ad- that, as a tube an inch in diameter may , the influence of capillarity becomes inap- e. Its construction moreover is very simple, position of the scale leads to no kind of ce this is transferred to the cathetometer. nately the latter instrument requires great in its construction, and is very expensive.

etermination of heights by the barometer.—Since the atmo- ressure decreases as we ascend, it is obvious that the barometer on falling as it is taken to a greater and greater height—a fact uggests a very useful method of determining the difference between the elevations of two stations, such as the base and summit o mountain. The method may be explained as follows.

It will be seen in the next chapter that if the temperature of an enclo portion of air continues constant, its volume will vary inversely as pressure. That is to say, if we double the pressure we shall halve volume. This is usually known as Boyle's law (166). But if halve the volume we manifestly double the quantity of air in ea cubic inch, that is to say, we double the density of the air, and so in any proportion. Consequently, the law is equivalent to this: That for a constant temperature the density of air is proportion to the pressure which it sustains.

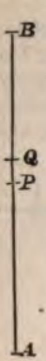

Fig. 114.

Now suppose A and B (fig. 114) to represent two stations, an that it is required to determine the vertical height of B above A it being borne in mind that A and B are not necessarily in t same vertical line. Take P any point in AB, and Q a point at small distance above P. Suppose the pressure per square inch the atmosphere at P to be denoted by p, and at Q let it b diminished by a quantity denoted by dp. It is plain that th diminution equals the weight of the column of air between P an Q, whose section is one square inch. But, since the density of th air is directly proportional to p, the weight of a cubic inch of ai will equal kgp, where k denotes a certain quantity to be determined here after, and g the accelerating force of gravity (74). Hence, if we denot PQ in inches by dx, the pressure will be diminished by $kpg.dx$, and w may represent this fact algebraically by the equation

$$kpg.dx = dp.$$

By a well-known algebraical process this leads to the conclusion tha

$$kgX = \log \frac{P}{P_1}$$

where X denotes the height of AB, and P and P_1 the atmospher pressures at A and B respectively, the logarithms being of the kin called 'Napierian logarithms.' Now, if H and H_1 are the heights o the barometer at A and B respectively, the temperature of the mercur being the same at both stations, their ratio equals that of P to P_1, an therefore

$$X = \frac{1}{kg} \cdot \log \frac{H}{H_1}$$

It remains to determine k and g.

(1) Since the force of gravity is different for places in different lat tudes, g will depend upon the latitude (77). It is found that if g is th accelerating force of gravity in latitude ϕ, and f that force in latitude 45 then

$$g = \frac{f}{1 + 0·00256 \cos 2\phi}$$

where f has a definite numerical value.

(2) From what has been stated above it will be seen, that if ρ is th

ity of air at a temperature of $t°$ C., under Q the pressure exerted by inches of mercury, we shall have

$$kQ = \rho$$

it will be afterwards shown that if ρ_0 is the density of air under the pressure Q at 0° C., we shall have

$$\rho = \frac{\rho_0}{1 + at}$$

ere a has a definite numerical value. Therefore

$$kQ = \frac{\rho_0}{1 + at}$$

ow if σ is the density of mercury, and if the latitude is 45°, we shall e

$$Q = 29{\cdot}92 \ . \ \sigma f;$$

therefore

$$kf = \frac{\rho_0}{\sigma} \cdot \frac{1}{29{\cdot}92\,(1 + at)}$$

r $\rho_0 \div \sigma$ is the ratio which the density of dry air at a temperature 0° C., titude 45°, under a pressure of 29·92 inches of mercury, bears to the sity of mercury at 0° C., and therefore $\rho_0 \div \sigma$ is a determinate number. bstituting, we have

$$X = 29{\cdot}92 \text{ in. } . \frac{\sigma}{\rho_0}(1 + 0{\cdot}00256 \cos 2\phi).\ (1 + at) \log \frac{H}{H_1}$$

e value of a is 0·003665, which is nearly equal to $\frac{4}{1000}$. If we substitute e proper values for $\sigma \div \rho_0$, and change the logarithms into common logithms, and instead of t use the mean of T and T_1, the temperatures at e upper and lower stations, it will be found that

$$X \text{ (in feet)} = 60346\ (1 + 0{\cdot}00256 \cos 2\ \ )\left(1 + \frac{2(T + T_1)}{1000}\right) \log \frac{H}{H_1}$$

hich is La Place's barometric formula. In using it, it must be rememred that T and T_1 are temperatures on the Centigrade thermometer, d that H and H_1 are the heights of the barometer reduced to 0° C. hus if h is the measured height of the barometer at the lower station e have

$$H = h\left(1 - \frac{t}{6500}\right)$$

If the height to be measured is not great, one observer is enough. For eater heights the ascent takes some time, and in the interval the presre may vary. Consequently in this case there must be two observers, e at each station, who make simultaneous observations.

Let us take the following example of the above formula :—Suppose at in latitude 65° N. at the lower of the two stations the height of the rometer were 30·025 inches, and the temperature of air and mercury °·32 C., while at the upper the height of the barometer was 28·230 hes, and the temperature of air and mercury was 10°·55 C. Determine e height of the upper station above the lower.

(1) Find H and H_1: viz.

$$H = 30{\cdot}025\left(1 - \frac{17{\cdot}32}{6500}\right) = 29{\cdot}945$$

$$H_1 = 28{\cdot}230\left(1 - \frac{10{\cdot}55}{6500}\right) = 28{\cdot}184$$

$$\text{Hence } \log\frac{H}{H} = 1{\cdot}4763243 - 1{\cdot}4500026 = 0{\cdot}0263217$$

(2) Find $1 + \frac{2(T + T_1)}{1000}$ viz. $1{\cdot}05574$

(3) Find $1 + 0{\cdot}00256 \cos 2\phi$

Since $0{\cdot}00256 \cos 130° = -0{\cdot}00256 \cos 50°$

$$= -0{\cdot}001645$$

therefore $1 + 0{\cdot}00256 \cos 2\phi = 0{\cdot}998355$

Hence the required height in feet equals

$$60346 \times 0{\cdot}998355 \times 1{\cdot}05574 \times 0{\cdot}263217 = 1674$$

It may be easily proved that if H and H_1 do not greatly differ, the Napierian logarithm of $\frac{H}{H_1}$ equals $2\frac{H - H_1}{H + H_1}$. If for instance H equals 30 inches, and H_1 equals 29 inches, the resulting error would not exceed the $\frac{1}{5000}$ part of the whole. Accordingly for heights not exceeding 2000 ft. we may without much error use the formula,

$$X \text{ (in feet)} = 52500\left(1 + \frac{2(T + T_1)}{1000}\right) \times \frac{H - H_1}{H + H_1}$$

CHAPTER II.

MEASUREMENT OF THE ELASTIC FORCE OF GASES.

166. **Boyle's law.**—The law of the compressibility of gases was discovered by Boyle and Mariotte independently. In consequence it is in England commonly called 'Boyle's law,' and, on the Continent, 'Mariotte's law.' It is as follows:

'The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure which it bears.'

This law may be verified by means of an apparatus called *Mariotte's tube* (fig. 115). It consists of a long glass tube fixed to a vertical support; it is open at the upper part, and the other end, which is bent into a short vertical leg, is closed. On the shorter leg there is a scale, which indicates equal capacities; the scale against the long leg gives the heights. The zero of both scales is in the same horizontal line.

A small quantity of mercury is poured into the tube, so that its level in oth branches is at zero, which is effected without much difficulty after a ew trials (fig. 115). The air in the short leg is thus under the ordinary tmospheric pressure which is exerted through the open tube. Mercury s then poured into the longer tube until the volume of the air in the maller tube is reduced to one-half; that is, until it is reduced from 10 to 5, as shown in fig. 116. If the height of the mercurial column, CA, be easured, it will be found exactly equal to the height of the barometer at

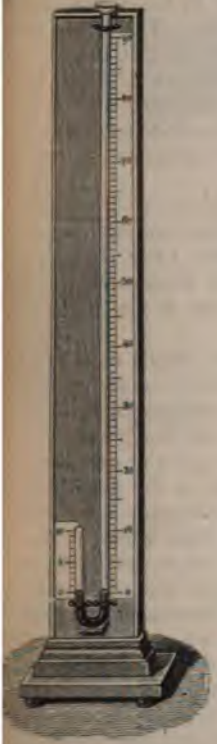
Fig. 115

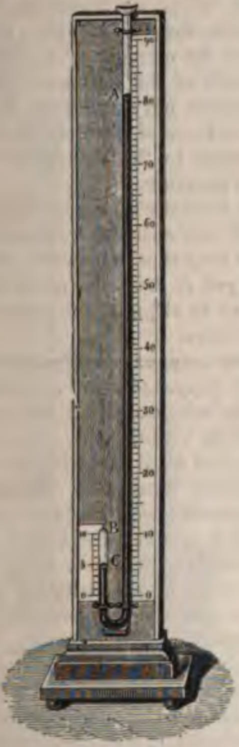

Fig. 116.

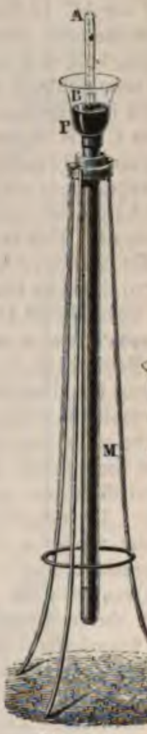

Fig. 117.

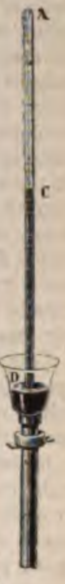

Fig. 118.

time of the experiment. The pressure of the column CA is therefore al to an atmosphere which, with the atmospheric pressure acting on surface of the column at C, makes two atmospheres. Accordingly, doubling the pressure, the volume of the gas has been diminished to half.

f mercury be poured into the longer branch until the volume of the s reduced to one-third its original volume, it will be found that the ance between the level of the two tubes is equal to two barometric mns. The pressure is now three atmospheres, while the volume is [illegible] and Petit have verified the law for air up [illegible] an apparatus analogous to that which [illegible]

[illegible] the case of pressures of less than one at- [illegible] mercury is poured into a graduated tube [illegible] the rest being air. It is then inverted in [illegible] mercury (fig. 117), and lowered until the levels [illegible] outside the tube are the same, and the volume [illegible] raised, as represented in the figure, until the [illegible] that of AB (fig. 118). The height of the [illegible] the mercury in the trough CD, is then found [illegible] of the barometric column. The air, whose [illegible] only under the pressure of half an atmo- [illegible] force of this air which, added to the weight of [illegible] to the atmospheric pressure. Hence the [illegible] pressure.

[illegible] Mariotte's tube, as the quantity of air remains [illegible] obviously increase as its volume diminishes, [illegible] may thus be enunciated: '*For the same tem-* [illegible] *is proportional to its pressure.*' Hence, as [illegible] as air, under a pressure of 770 atmospheres, [illegible] water.

[illegible] law is only approximately true. Until within the last [illegible] supposed to be absolutely true for all gases at [illegible] who examined the compressibility of gases, [illegible] with the law. He took two graduated glass [illegible] and filled one with air and the other with the [illegible] These tubes were placed in the same mercury [illegible] apparatus immersed in a strong glass cylinder filled [illegible] a piston moved by a screw which worked in [illegible] der, the liquid could be subjected to an in- [illegible] be seen whether the compression of the [illegible] The apparatus resembled that used for [illegible] of liquids (fig. 49). In this manner [illegible] acid, sulphuretted hydrogen, ammonia, [illegible] compressible than air: hydrogen, which has the [illegible] to 15 atmospheres, is then less compres- [illegible] it was concluded that the law of Boyle [illegible]

[illegible] elastic force of vapours, Dulong and Arago [illegible] of Boyle's law. The method adopted [illegible] that the apparatus had gigantic dimen- [illegible]

[illegible] contained in a strong glass tube, GF [illegible] closed at the top, G. The pressure was [illegible] which could be increased to a height [illegible] tical tube, KL, formed of a number of [illegible] so as to be perfectly tight.

The tubes KL and GF were hermetically fixed in a horizontal iron pipe, E, which formed part of a mercurial reservoir, A. On the top of this servoir there was a force pump, BC, by which mercury could be forced to the apparatus.

At the commencement of the experiment, the volume of the air in the anometer (171) was observed, and the initial pressure determined, by lding to the pressure of the atmosphere the height of the mercury in K

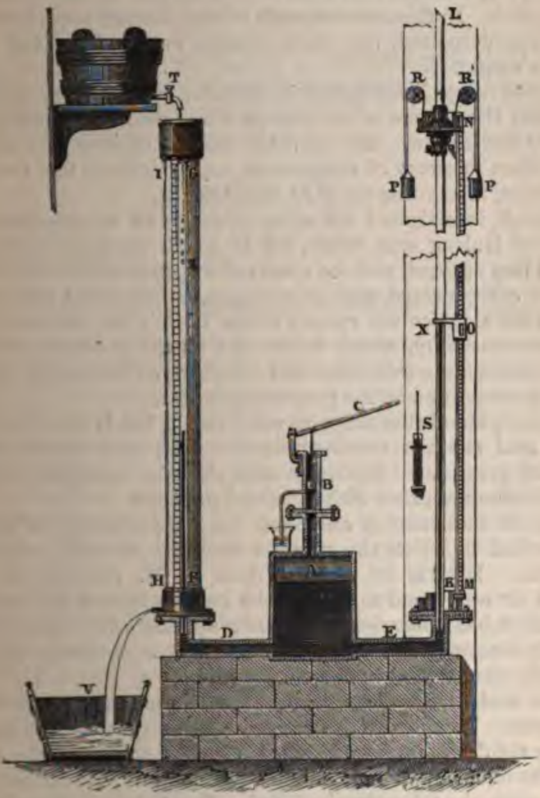

Fig. 119.

e its level in H. If the level of the mercury in the manometer had above the level in KL, it would have been necessary to subtract the ence.

means of the pump, water was injected into A. The mercury then pressed by the water, rose in the tube GF, where it compressed ir, and in the tube KL, where it rose freely. It was only then sary to measure the volume of the air in GF; the height of the mercury in KL above the level in GF, together with the pressure of the atmosphere, was the total pressure to which the gas was exposed. These were all the elements necessary for comparing different volumes and the corresponding temperatures. The tube GF was kept cold during the experiment by a stream of cold water.

The long tube was attached to a long mast by means of staples. The individual tubes were supported at the junction by cords, which passed round pulleys R and R′, and were kept stretched by small buckets, P, containing shot. In this manner, each of the thirteen tubes having been separately counterpoised, the whole column was perfectly free notwithstanding its weight.

Dulong and Arago investigated the pressure up to 27 atmospheres, and observed that the volume of air always diminished a little more than is required by Boyle's law. But as these differences were very small, they attributed them to errors of observation, and concluded that the law was perfectly exact, at any rate up to 27 atmospheres.

M. Regnault investigated the same subject with an apparatus resembling that of Dulong and Arago, but in which all the sources of error were taken into account, and the observations made with remarkable precision. He experimented with air, nitrogen, carbonic acid, and hydrogen. He found that air does not exactly follow Boyle's law, but experiences a greater compressibility, which increases with the pressure; so that the difference between the calculated and the observed diminution of volume is greater in proportion as the pressure increases.

M. Regnault found that nitrogen was like air, but is less compressible. Carbonic acid exhibits considerable deviation from Boyle's law even under small pressures. Hydrogen also deviates from the law, but its compressibility diminishes with increased pressure.

Recently M. Cailletet has examined the compressibility of gases by a special method in which the pressure could be carried as high as 600 atmospheres. His results confirm those of M. Regnault as regards hydrogen; air was found to present the curious feature that towards 80 atmospheres it has *a maximum relative compressibility*; beyond this point it gradually becomes less compressible; its compressibility diminishing more rapidly than that of hydrogen.

Carbonic acid deviates less from the law in proportion as the temperature is higher. This is also the case with other gases. And experiment shows that the deviation from the law is greater in proportion as the gas is nearer its liquefying point; and, on the contrary, the farther a gas is from this point, the more closely does it follow the law. For gases which have not been liquefied, the deviations from the law are inconsiderable and may be quite neglected in ordinary physical and chemical experiments, where the pressures are not great.

168. **Applications of Boyle's law.**—Observations on the volumes of gases are only comparable when made at the same pressure. Usually therefore, in gas analyses, all measurements are reduced to the standard pressure of 760 millimetres, or 29·92 inches. This is easily done by Boyle's law, for, since the volumes are inversely as the pressures

$V : V' = P' : P$. Knowing the volume V at the pressure P we can easily calculate its volume V′ at the given pressure P′, for

$$V'P' = VP$$

that is,

$$V' = \frac{VP}{P'}$$

Suppose a volume of gas to measure 340 cubic inches under a pressure of 535 mm., what will be its volume at the standard pressure, 760 mm.?

We have
$$V = \frac{340 \times 535}{760} = 238 \text{ cubic inches.}$$

In like manner let it be asked, if D′ is the density of a gas when the barometer stands at H′ mm., what will be its density D at the same temperature when the barometer stands at H mm.? Let M be the mass of the gas, V′ its volume in the first case, V its volume in the second. Therefore,

$$DV = M = D'V'$$

or,
$$\frac{D}{D'} = \frac{V'}{V} = \frac{P}{P'} = \frac{H}{H'}$$

Thus, if H′ denote 760 mm., we have

$$\text{Density at } H = (\text{Density at standard pressure}) \frac{H}{760}$$

169. **Manometers.**—Manometers are instruments for measuring the tension of gases or vapours. In all manometers the unit chosen is the pressure of one atmosphere or 30 inches of mercury at the standard temperature, which, as we have seen, is nearly 15lbs. to the square inch.

170. **Open-air manometer.**—The open-air manometer consists of a bent glass tube BD (fig. 120), fastened to the bottom of a reservoir AC, of the same material, containing mercury, which is connected with the closed recipient containing the gas or vapour the pressure of which is to be measured. The whole is fixed on a long plank kept in a vertical position.

In graduating this manometer C is left open, and the number 1 marked at the level of the mercury, for this represents one atmosphere. From this point the numbers 2, 3, 4, 5, 6 are marked at each 30 inches, indicating so many atmospheres, since a column of mercury 30 inches represents a pressure of one atmosphere. The intervals from 1 to 2, and from 2 to 3, &c., are divided into tenths. C being then placed in connection with a boiler, for example, the mercury rises in the tube BD to a height which measures the tension of the vapour. In the figure the manometer marks 2 atmospheres, which represents a height of 30 inches, plus the atmospheric pressure exerted at the top of the column through the aperture D.

This manometer is only used when the pressures do not exceed 5 to 6 atmospheres. Beyond this, the length of tube necessary makes it very venient, and the following apparatus is commonly used.

. **Manometer with compressed air.**—The *manometer with com- d air* is founded on Boyle's law; it consists of a glass tube closed top, and filled with dry air. It is firmly cemented in a small iron box containing mercury. By a tubulure, A, in the side (fig. 121), this box is connected with the closed vessel containing the gas or whose tension is to be measured.

In the graduation of this manometer, the quantity of air cont the tube is such, that when the aperture A communicates freely atmosphere, the level of the mercury is the same in the tube an tubulure. Consequently, at this level, the number 1 is marked

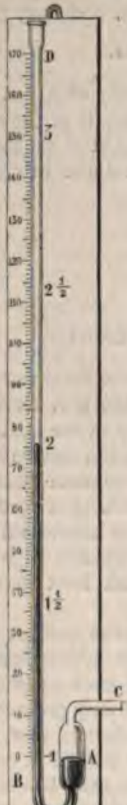

Fig. 120.

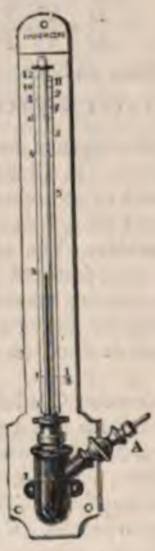

Fig. 121.

Fig. 122.

scale to which the tube is affixed. As the pressure acting thr tubulure A increases, the mercury rises in the tube, until its weigh to the tension of the compressed air, is equal to the external It would consequently be incorrect to mark two atmospheres middle of the tube; for since the volume of the air is reduced to its tension is equal to two atmospheres, and, together, with the the mercury raised in the tube, is therefore more than two atm The position of the number is a little below the middle, at such that the elastic force of the compressed air, together with the weight of the mercury in the tube, is equal to two atmospheres. The exact position of the numbers 2, 3, 4, &c. on the manometer scale can only be determined by calculation. Sometimes this manometer is made of one glass tube, as represented in fig. 122. The principle is obviously the same.

172. **Regnault's barometric manometer.**—For measuring pressures of less than one atmosphere, M. Regnault has the following arrangement, which is a modification of his fixed barometer (fig. 113). In the same cistern dips a second tube *a*, of the same diameter, open at both ends, and provided at the top with a three-way cock, one of which is connected with an air pump and the other with the space to be exhausted. The farther the exhaustion is carried the higher the mercury rises in the tube *a*. The difference of level in the tubes *b* and *a* gives the pressure. Hence, by measuring the height *ab*, by means of the cathetometer, the pressure in the space that is being exhausted is accurately given. This apparatus is also called the *differential barometer*.

173. **Aneroid barometer.**—This instrument derives its name from the circumstance that no liquid is used in its construction (ἀ, without, νηρὸς, moist). Fig. 123 represents one of the forms of these instruments, constructed by Mr. Casella: it consists of a cylindrical metal box, exhausted of air, the top of which is made of thin corrugated metal, so elastic that it readily yields to alterations in the pressure of the atmosphere.

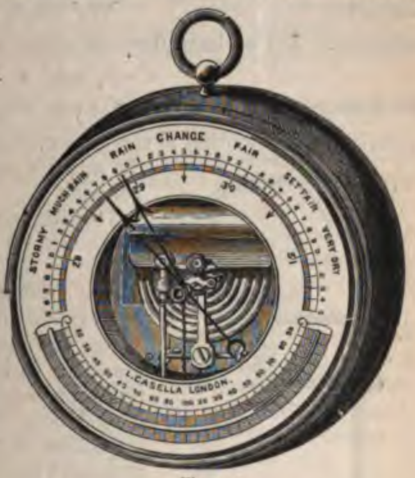

Fig. 123.

When the pressure increases, the top is pressed inwards; when on the contrary it decreases, the elasticity of the lid, aided by a spring, tends to move it in the opposite direction. These motions are transmitted by delicate multiplying levers to an index which moves on a scale. The instrument is graduated empirically by comparing its indications under different pressures with those of an ordinary mercurial barometer.

The aneroid has the advantage of being portable, and can be constructed of such delicacy as to indicate the difference in pressure between the height of an ordinary table and the ground. It is hence much used in determining heights in mountain ascents. But it is liable to get out of order, especially when it has been subjected to great variations of pressure; and its indications must from time to time be compared by means of a standard barometer.

174. **Laws of the mixture of gases.**—If a communication is opened

between two closed vessels containing gases, they at once begin to mix, whatever be their density, and in a longer or shorter time the mixture is complete, and will continue so, unless chemical action or some other extraneous cause intervene. The laws which govern the mixture of gases may be thus stated :

I. *The mixture takes place rapidly and is homogeneous, that is, each portion of the mixture contains the two gases in the same proportion.*

II. *If the gases severally and the mixture have the same temperature and if the gases severally and the mixture occupy the same volume, then the pressure on the unit of area exerted by the mixture will equal the sum of pressures on the unit of area exerted by the gases severally.*

From the second law a very convenient formula can be easily deduced. Let v_1, v_2, v_3 . . . . be the volumes of several gases under pressure p_1, p_2, p_3 . . . . respectively. Suppose these gases when mixed to have a volume V, under a pressure P, the temperatures being the same. By Boyle's law we know that v_1 will occupy a volume V under a pressure p_1' provided

$$Vp_1' = v_1 p_1$$

Similarly

$$Vp_2' = v_2 p_2$$

and so on. But we learn from the above law that

$$P = p_1' + p_2' + \ldots$$

therefore

$$VP = v_1 p_1 + v_2 p_2 + v_3 p_3 + \ldots$$

It obviously follows that if the pressures are all the same, the volume of the mixture equals the sum of the separate volumes.

The first law was shown experimentally by Berthollet, by means of an apparatus represented in fig. 124. It consists of two glass globes provided with stopcocks, which can be screwed one on the other. The upper globe was filled with hydrogen, and the lower one with carbonic acid, which has 22 times the density of hydrogen. The globes having been fixed together were placed in the cellars of the Paris Observatory and the stopcocks then opened, the globe containing hydrogen being uppermost. Berthollet found after some time that the pressure had not changed, and that, in spite of the difference in density, the two gases had become uniformly mixed in the two globes. Experiments made in the same manner with other gases gave the same results, and it was found that the diffusion was more rapid in proportion as the difference between the densities was greater.

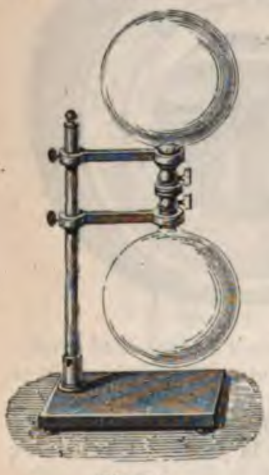

Fig. 124.

The second law may be demonstrated by passing into a graduated tube, over mercury, known volumes of gas at known pressures. The pressure and volume of the whole mixture are then measured, and found to be in accordance with the law.

Gaseous mixtures follow Boyle's law, like simple gases, as has been proved for air (163), which is a mixture of nitrogen and oxygen.

175. **Mixture of gases and liquids. Absorption.**—Water and many liquids possess the property of absorbing gases. Under the same conditions of pressure and temperature a liquid does not absorb equal quantities of different gases. At the ordinary temperature and pressure water dissolves $\frac{25}{1000}$ its volume of nitrogen, $\frac{46}{1000}$ its volume of oxygen, its own volume of carbonic acid, and 430 times its volume of ammoniacal gas.

The whole subject of gas absorption has been investigated by Bunsen, to whose work* the student is referred for further information. The general laws of gas-absorption are the following:—

I. *For the same gas, the same liquid, and the same temperature, the weight of gas absorbed is proportional to the pressure.* This may also be expressed by saying that at all pressures the volume dissolved is the same; so that the density of the gas absorbed is in a constant relation with that of the external gas which is not absorbed.

Accordingly, when the pressure diminishes, the quantity of dissolved gas decreases. If a solution of gas be placed under the air-pump and a vacuum created, the gas obeys its expansive force and escapes with effervescence.

II. *The quantity of gas absorbed is greater when the temperature is lower*; that is to say, when the elastic force of the gas is less.

III. *The quantity of gas which a liquid can dissolve is independent of the nature and of the quantity of other gases which it may already hold in solution.*

In every gaseous mixture each gas exercises the same pressure as it would if its volume occupied the whole space; and the total pressure is equal to the sum of the individual pressures. When a liquid is in contact with a gaseous mixture, it absorbs a certain part of each gas, but less than it would if the whole space were occupied by each gas. The quantity of each gas dissolved is proportional to the pressure which the unabsorbed gas exercises alone. For instance, oxygen forms only about $\frac{1}{5}$ the quantity of air; and water, under ordinary conditions, absorbs exactly the same quantity of oxygen as it would if the atmosphere were entirely formed of this gas under a pressure equal to $\frac{1}{5}$ that of the atmosphere.

CHAPTER III.

PRESSURE ON BODIES IN AIR. BALLOONS.

176. **Archimedes' principle applied to gases.**—The pressure exerted by gases on bodies immersed in them is transmitted equally in all directions, as has been shown by the experiment with the Magdeburg hemi-

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* Gasometric Methods, by R. Bunsen, translated by Prof. Roscoe.

spheres. It therefore follows that all which has been said equilibrium of bodies in liquids applies to bodies in air ; they l of their weight equal to that which they displace.

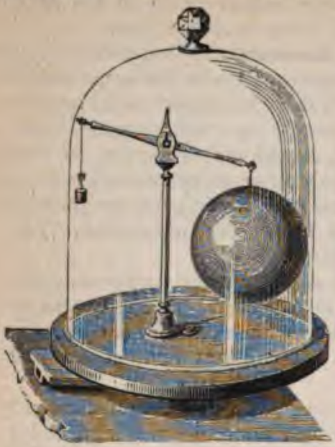


Fig. 125.

The loss of weight in air is strated by means of the which consists of a scalebea of whose extremities a sma weight is supported, and at there is a hollow coppe (fig. 125). In the air they balance one another ; but w are placed under the receive air pump and a vacuum is the sphere sinks ; thereby that in reality it is heavier small leaden weight. Befor is exhausted each body is bu by the weight of the air whic places. But as the sphere is larger of the two, its weight u most apparent diminution, a though in reality the heavier body, it is balanced by the smal weight. It may be proved by means of the same apparatus that is equal to the weight of the displaced air. Suppose the volum sphere is 10 cubic inches. This weight of this volume of air is 3· If now this weight be added to the leaden weight, it will overbal sphere in air, but will exactly balance it in vacuo.

The principle of Archimedes is true for bodies in air ; all that said about bodies immersed in liquids applies to them, that is, th a body is heavier than air, it will sink, owing to the excess of its over the buoyancy. If it is as heavy as air, its weight will exactly balance the buoyancy, and the body will float in the atmosphere. body is lighter than air, the buoyancy of the air will prevail, and will rise in the atmosphere until it reaches a layer of the same de its own. The force of the ascent is equal to the excess of the b over the weight of the body. This is the reason why smoke, clouds, and air balloons rise in the air.

AIR BALLOONS.

177. **Air balloons.**—*Air balloons* are hollow spheres made light impermeable material, which, when filled with heated a hydrogen gas, or with coal gas, rise in the air in virtue of their lightness.

They were invented by the brothers Mongolfier, of Annonay, first experiment was made at that place in June 1783. Their ball a sphere of 40 yards in circumference, and weighed 500 pounds.

lower part there was an aperture, and a sort of boat was suspended, in which fire was lighted to heat the internal air. The balloon rose to a height of 1,200 yards, and then descended without any accident.

Charles, a professor of physics in Paris, substituted hydrogen for hot air. He himself ascended in a balloon of this kind in December 1783. The use of hot air balloons was entirely given up in consequence of the serious accidents to which they were liable.

Since then, the art of ballooning has been greatly extended, and many ascents have been made. That which Gay-Lussac made in 1804 was the most remarkable for the facts with which it has enriched science, and for the height which he attained—23,000 feet above the sea level. At this height the barometer descended to 12·6 inches, and the thermometer, which was 31° C. on the ground, was 9 degrees below zero.

In these high regions, the dryness was such on the day of Gay-Lussac's ascent, that hygrometric substances, such as paper, parchment, etc., became dried and crumpled as if they had been placed near the fire. The respiration and circulation of the blood were accelerated in consequence of the great rarefaction of the air. Gay-Lussac's pulse made 120 pulsations in a minute, instead of 66, the normal number. At this great height the sky had a very dark blue tint, and an absolute silence prevailed.

One of the most remarkable of recent ascents was made by Mr. Glaisher and Mr. Coxwell, in a large balloon belonging to the latter. This was filled with 90,000 cubic feet of coal gas (sp. gr. 0·37 to 0·33); the weight of the load was 600 pounds. The ascent took place at 1 p.m. on September 5, 1861; at 1° 28′ they had reached a height of 15,750 feet, and in eleven minutes after a height of 21,000 feet, the temperature being −10·4; at 1° 50′ they were at 26,200 feet, with the thermometer at −15·2°. At 1° 52′ the height attained was 29,000 feet, and the temperature −16·0 C. At this height the rarefaction of the air was so great, and the cold so intense, that Mr. Glaisher fainted, and could no longer observe. According to an approximate estimation the lowest barometric height they attained was 7 inches, which would correspond to an elevation of 36,000 o 37,000 feet.

178. **Construction and management of balloons.**—A balloon is made f long bands of silk sewed together and covered with caoutchouc varnish, hich renders it air-tight. At the top there is a safety valve closed by a pring which the aëronaut can open at pleasure, by means of a cord. A ght wicker-work boat is suspended by means of cords to a net-work, hich entirely covers the balloon.

A balloon of the ordinary dimensions, which can carry three persons, about 16 yards high, 12 yards in diameter, and its volume when it is ite full is about 680 cubic yards. The balloon itself weighs 200 pounds; e accessories, such as the rope and boat, 100 pounds.

The balloon is filled either with hydrogen or with coal gas. Although e latter is heavier than the former, it is generally preferred, because it cheaper and more easily obtained. It is passed into the balloon from e gas reservoir by means of a flexible pipe. It is important not to fill e balloon quite full, for the atmospheric pressure diminishes as it rises (fig. 126), and the gas inside expanding in consequence of its elastic force, tends to burst it. It is sufficient for the ascent if the weight of the displaced air exceeds that of the balloon by 8 or 10 pounds. And this force remains constant so long as the balloon is not quite distended by the dilatation of the air in the interior. If the atmospheric pressure, for example, has diminished to one-half, the gas in the balloon, according to Boyle's law, has doubled its volume. The volume of the air displaced is therefore twice as great; but, since its density has become only one-half, the weight, and consequently the upward buoyancy, are the same. When once the balloon is completely dilated, if it continue to rise the force of the ascent decreases, for the volume of the displaced air remains the same, but its density diminishes, and a time arrives at which the buoyancy is equal to the weight of the balloon. The balloon can now only take a horizontal direction, carried by the currents of air which prevail in the atmosphere. The aëronaut knows by the barometer whether he is ascending or descending; and by the same means he determines the height which he has reached. A long flag fixed to the boat would indicate, by the position it takes either above or below, whether the balloon is descending or ascending.

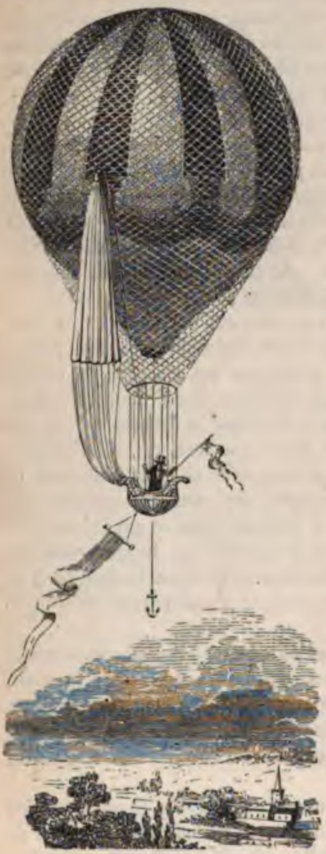


Fig. 126.

When the aëronaut wishes to descend, he opens the valve at the top of the balloon by means of the cord, which allows gas to escape, and the balloon sinks. If he wants to descend more slowly, or to rise again, he empties out bags of sand, of which there is an ample supply in the car. The descent is facilitated by means of a grappling iron fixed to the boat. When once this is fixed to any obstacle, the balloon is lowered by pulling the cord.

The only practical applications which air balloons have hitherto had have been in military reconnoitring. At the battle of Fleurus, in 1794, a captive balloon, that is, one held by a cord, was used, in which there was a observer who reported the movements of the enemy by means of signals At the battle of Solferino the movements and dispositions of the Austria troops were watched by a captive balloon; and in the war in Americ balloons were frequently used, while their importance during the siege of Paris is fresh in all memories. The whole subject of military ballooning has been treated in two papers by Lieut. Groves and by Captain Beaumont, in a recent volume of the Professional Papers of the Royal Engineers. Many ascents have recently been made by Mr. Glaisher for the purpose of making meteorological observations in the higher regions of the atmosphere. Air balloons can only be truly useful when they can be guided, and as yet all attempts made with this view have completely failed. There is no other course at present than to rise in the air until there is a current which has more or less the desired direction.

179. **Parachute.**—The object of the parachute is to allow the aëronaut to leave the balloon, by giving him the means of lessening the rapidity of his descent. It consists of a large circular piece of cloth (fig. 127) about 16 feet in diameter, and which by the resistance of the air spreads out like a gigantic umbrella. In the centre there is an aperture, through which the air compressed by the rapidity of the descent makes its escape; for otherwise oscillations might be produced, which, when communicated to the boat, would be dangerous.

In fig. 126 there is a parachute attached to the net-work of the balloon by means of a cord which passes round a pulley, and is fixed at the other end to the boat. When the cord is cut the parachute sinks, at first very rapidly, but more slowly as it becomes distended, as represented in the figure.

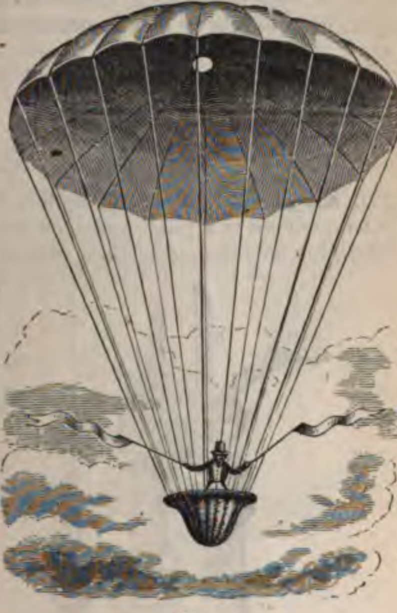


Fig. 127.

180. **Calculation of the weight which a balloon can raise.**—To calculate the weight which can be raised by a balloon of given dimensions let us suppose it perfectly spherical, and premise that the formulæ which express the volume and the superficies in terms of the radius are $V=\frac{4\pi R^3}{3}$ and $S=4\pi R^2$, π being the ratio of the circumference to the diameter, and equal to 3·1416. The radius R being measured in feet, let p be, in pounds, the weight of a square foot of the material of which the balloon is constructed; let P be the weight of the car and the accessories, the weight in pounds of a cubic foot of air at zero, and under the pressure 0·76, and *a* the weight of the same volume under the same con-

ditions of the gas with which the balloon is inflated (144). Then the total weight of the envelope in pounds will be $4\pi R^2 p$; that of the gas will be $\frac{4\pi R^3 a'}{3}$, and that of the displaced air $\frac{4\pi R^3 a}{3}$. If X be the weight which the balloon can support, we have

$$X = \frac{4\pi R^3 a}{3} - \frac{4\pi R^2 a'}{3} - 4\pi R^2 p - P.$$

Whence

$$X = \frac{4\pi R^3}{3}(a - a') - 4\pi R^2 - P.$$

But, as we have before seen (178), in order that the balloon may rise, the weights must be less by 8 or 10 pounds than that given by this equation.

CHAPTER IV.

APPARATUS FOUNDED ON THE PROPERTIES OF AIR.

181. **Air pump.**—The air pump is an instrument by which a vacuum can be produced in a given space, or rather by which air can be greatly rarefied, for an absolute vacuum cannot be produced by its means. It was invented by Otto von Guericke in 1650, a few years after the invention of the barometer.

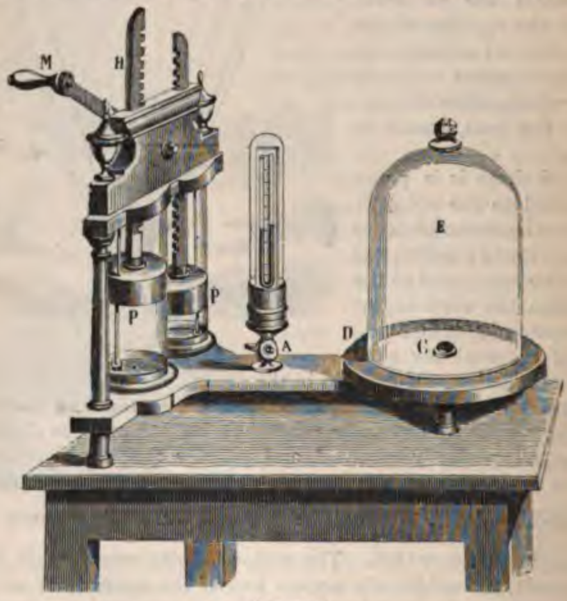


Fig. 123.

The air pump, as now usually constructed, may be described as follows: In fig. 128, which shows the general arrangement, E is the *receiver*, in which the vacuum is to be produced. It is a bell glass, resting on a plate D, of thick glass ground perfectly smooth. In the centre of D, at C, there is an opening by which a communication is made between the interior of the receiver and of the cylinders P, P. This communication is effected by a tube or pipe passing through the body of the plate A, and then branching off at right angles, as shown by *Kco Kcs*, in fig. 129, which represents a horizontal section of the machine. In the cylinders—which are commonly of glass, and which are firmly cemented to the plate A—are two pistons, P and Q, fitting air-tight. Each piston is moved by a rack, working with a pinion, H, turned by a handle, M. This is shown more plainly in fig. 130, which represents a vertical section of the machine through the cylinders: here H is the pinion, and MN the handle. When M is forced down one piston is raised, and the other depressed. When M's action is reversed, the former piston is depressed, and the latter raised.

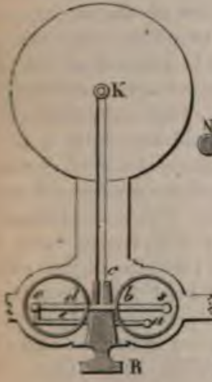


Fig. 129.

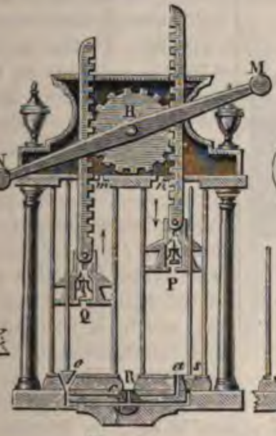


Fig. 130.

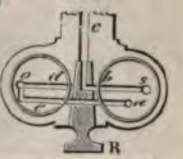


Fig. 132.

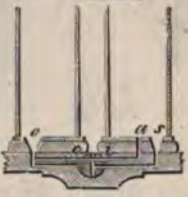


Fig. 131.

The action of the machine is this: Each cylinder is fitted with a valve so contrived that when its piston is raised, communication is opened between the cylinder and the receiver: when it is depressed the communication is closed. Now if P were simply raised, a vacuum would be formed below P; but as a communication is opened with the receiver E, the air in E expands so as to fill both the receiver and the cylinder. As soon as the piston begins to descend, the communication is closed, and none of the air in the cylinder returns to the receiver, but, by means of properly constructed valves, escapes into the atmosphere. Consequently the rarefaction which the air in the receiver has undergone is permanent. By the next stroke a further rarefaction is produced; and so on, at each succeeding stroke.

It is plain that when the rarefaction has proceeded to a considera extent the atmospheric pressure on the top of P will be very great, bu will be very nearly balanced by the atmospheric pressure on the top the other piston. Consequently the experimenter will have to overco only the difference of the two pressures. This is the reason why t cylinders are employed.

To explain the action of the valves we must go into particulars. Th general arrangement of the interior of the cylinders is shown in fig. 13 Fig. 133 shows the section of the piston i detail. The piston is formed of two bras discs (X and V), screwed to one another, and compressing between them a series of leather discs Z, whose diameters are slightly greater than those of the brass discs. The leather is thoroughly saturated with oil, so as to slide air-tight, though with but little friction, within the cylinder. To the centre of the upper disc is screwed a piece, B, to which the rack H is riveted. The piece B is pierced so as to put the interior of the cylinder into communication with the external air. This communication is closed by a valve *t*, held down by a delicate spring, *r*. When the piston is moved downward the air below the piston is compressed until it forces up *t* and escapes. The instant the action is reversed, the valve *t* falls, and is held down by the spring, and the pressure of the external air, which is thereby kept from coming in. The communication between the cylinder below the piston and the receiver is opened and closed by the valve marked *o* in fig. 130, and *sg* in fig. 133. The rod passing through the piston is held by friction, and is raised with it; but is kept from being lifted through more than a very small distance by the top of the cylinder, while the piston, in continuing its upward motion slides over *sg*. When the piston descends it brings the valve with it which at once cuts off the communication between the cylinder and th receiver.

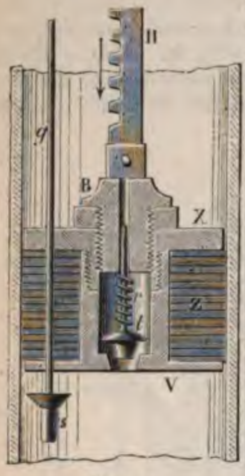


Fig. 133.

182. **Air pump gauge.**—When the pump has been worked some time the pressure in the receiver is indicated by the difference of level of th mercury in the two legs of a glass tube bent like a syphon, one of whic is opened, and the other closed like the barometer. This little apparatus which is called the *gauge*, is fixed to an upright scale, and placed unde a small bell jar, which communicates with the receiver E by a stop cock, A, inserted in the tube leading from the orifice C to the cylinder fig. 128.

Before commencing to exhaust the air in the receiver, its elastic forc exceeds the weight of the column of mercury, which is in the close branch and which consequently remains full. But as the pump worked, the elastic force soon diminishes, and is unable to support the weight of the mercury, which sinks and tends to stand at the same level in both legs. If an absolute vacuum could be produced, they would be exactly on the same level, for there would be no pressure either on the one side or the other. But with the very best machines the level is always about a thirtieth of an inch higher in the closed branch, which indicates that the vacuum is not absolute, for the elastic force of the residue is equal to the pressure of a column of mercury of that height.

Practically the machine can never give an absolute vacuum, for, as we have seen, the air becomes ultimately so rarefied that, when the pistons are at the bottom of the cylinder, its elastic force cannot overcome the pressure on the valves in the inside of the piston, which, therefore, do not open.

Theoretically an absolute vacuum is also impossible; for, since the volume of each cylinder is, say, $\frac{1}{20}$ that of the receiver, only $\frac{1}{21}$ of the air in the receiver is extracted at each stroke of the piston, and consequently it is impossible to exhaust all the air which it contains. The theoretical degree of exhaustion after a given number of strokes is easily calculated as follows :—Let A denote the volume of the receiver, including in that term the pipe; B the volume of the cylinder between the highest and lowest positions of the piston; and assume for the sake of distinctness that there is only one cylinder; then the air which occupied A before the piston is lifted occupies A + B after it is lifted, and consequently if D_1 is the density at the end of the first stroke and D the original density, we must have

$$D_1 = D\frac{A}{A+B}$$

If D_2 is the density at the end of the second stroke, we have for just the same reason

$$D_2 = D_1\frac{A}{A+B} = D\left(\frac{A}{A+B}\right)^2$$

Now this reasoning will apply to *n* strokes;

consequently $$D_n = D\left(\frac{A}{A+B}\right)^n$$

If there are two equal cylinders, the same formula holds, but in this case, in counting *n*, upstrokes and downstrokes equally reckon as *one*.

It is obvious that the exhaustion is never complete, since D_n can be zero only when *n* is infinite. However, a number of strokes not excessively great would render the exhaustion virtually complete, even if A is several times greater than B. Thus if A = 10 B, a hundred strokes will reduce the density from D to 0·0004 D; that is, if the initial pressure is 30 in., the pressure at the end of 100 strokes is 0·012 of an inch.

Practically, however, a limit is placed on the rarefaction that can be produced by any given machine; for, as we have seen, the air becomes ultimately so rarefied that, when the pistons are at the bottom of the cylinder, its elastic force cannot overcome the pressure on the valves in the inside of the piston; they therefore do not open, and there is no further action of the machine.

183. **Doubly-exhausting stopcock.**—M. Babinet has invented an improved stopcock, by which the exhaustion of the air can be carried to a very high degree. This stopcock is placed in the fork of the pipe leading from the receiver to the two cylinders; it is perforated by several channels, which are successively used by turning it into two different positions. Fig. 129 represents a horizontal section of the stopcock R, in such a position that, by its central opening and two lateral openings, it forms a communication between the orifice K of the plate, and the two valves *o* and *s*. The machine then works as has been described. In fig. 132 the stopcock has been turned a quarter, and the transversal channel *db*, which was horizontal in fig. 129, is now vertical, and its extremities are closed by the side of the hole in which the stopcock works. But a second channel, which was closed before, and which has taken the place of the first, now places the right cylinder, *alone* in communication with the receiver by the channel *cbs* (fig. 132), and it further connects the right with the left cylinder by a channel, *aeo* (fig. 132), or *aico* (fig. 131). This channel passes from a central opening *a*, placed at the base of the right cylinder, across the stopcock to the valve *o*, of the other cylinder, as represented in figs. 131 and 132; but this channel is closed by the stopcock when it is in its first position, as is seen in figs. 129 and 130.

The right piston in rising exhausts the air of the receiver, but when it descends the exhausted air is driven into the left cylinder through the orifice *a*, the channel *io*, and the valve *o* (fig. 131), which is open. When the same piston rises, that of the left sinks; but the air which is above it does not return into the right cylinder, because the valve *o* is now closed. As the right cylinder continues to exhaust the air in the receiver, and to force it into the left cylinder, the air accumulates here, and ultimately acquires sufficient tension to raise the valve of the piston Q, which was impossible before the stopcock was turned, for it is only when the valves in the piston no longer open, that a quarter of a turn is given to the stopcock.

184. **Bianchi's air pump.**—M. Bianchi has invented an air pump which has several advantages. It is made entirely of iron, and it has only one cylinder, which oscillates in a horizontal axis fixed at its base, as seen in fig. 134. A horizontal shaft, with heavy fly-wheel, V, works in a frame, and is turned by a handle, M. A crank, *m*, which is joined to the top of the piston-rod, is fixed to the same shaft, and consequently at every revolution of the wheel the cylinder makes two oscillations.

In some cases, as in that shown in the figure, the crank and the fly-wheel are on parallel axes connected by a pair of cog-wheels. The modification in the action produced by this arrangement is as follows:—If the cog-wheel on the former axis has twice as many teeth as that on the latter axis, the pressure which raises the piston is doubled: an advantage which is counterbalanced by the inconvenience that now the piston will make one oscillation for one revolution of the fly-wheel.

The machine is double acting; that is, the piston PP (fig. 135) pro-
ces a vacuum both in ascending and descending. This is effected by
e following arrangements :—In the piston there is a valve, *b*, opening
pwards as in the ordinary machine. The piston rod AA is hollow, and
the inside there is a copper tube, X, by which the air makes its escape
rough the valve *b*. At the top of the cylinder there is a second valve

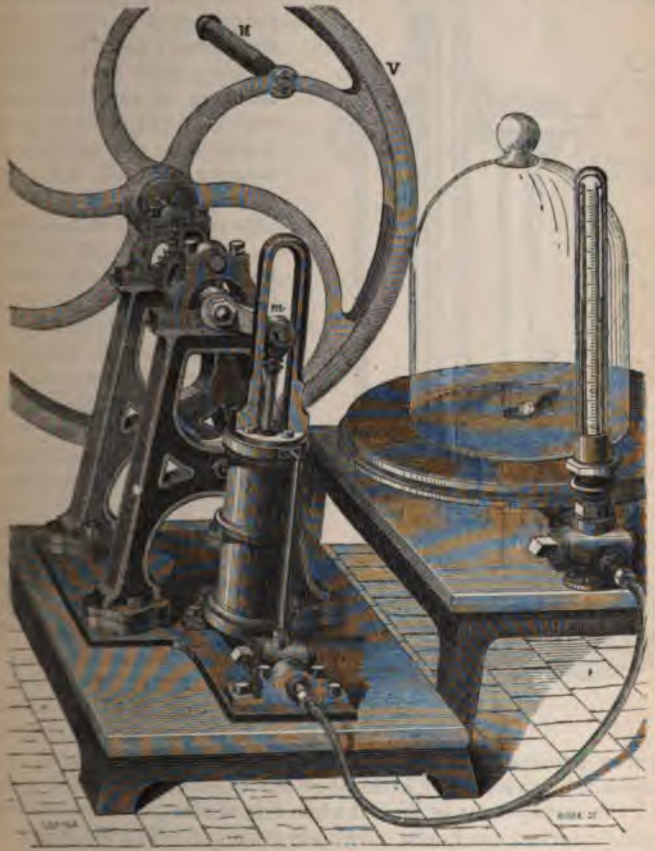


Fig. 134.

opening upwards. An iron rod, D, works with gentle friction in the
ton, and terminates at its ends in two conical valves, *s* and *s′*, which
into the openings of the tube BC leading to the receiver.
Let us suppose the piston descends. The valve *s′* is then closed, and
valve *s* being open, the air of the receiver passes in the space above
piston, while the air in the space below the piston undergoes com-

pression, and raising the valve, escapes by the tube X, which nicates with the atmosphere. When the piston ascends, the e takes place through *s'*, vale *s* being closed, t pressed air escapes by *a*.

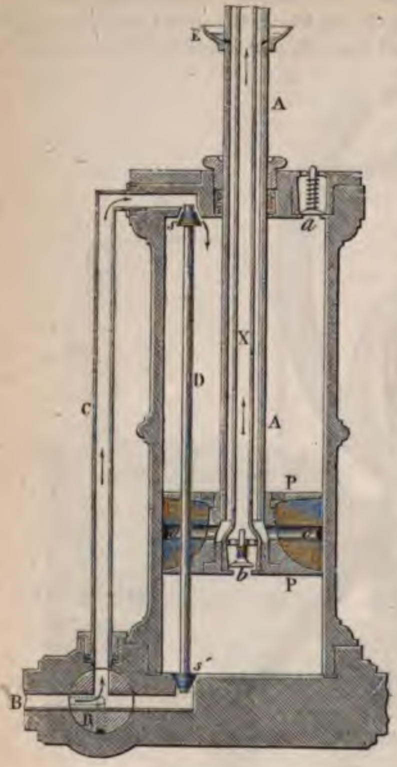


Fig. 135.

The machine has a for double exhaustion, that already described is also oiled in an i manner. A cup, E, r rod is filled with oi passes into the annul between the rod AA tube X; it passes the tube *oo*, in the piston, a by the atmospheric pr uniformly distributed o face of the piston.

The apparatus is of can consequently be much greater dimensi the ordinary machine cuum can also be with it in far less tim apparatus of greater usual.

185. **Sprengel's air** Sprengel has devised a air pump which depen principle of converting to be exhausted into cellian vacuum. The construction of the appa thus described by the i

If an aperture be ma top of a barometer tube, the mercury sinks and draws in ai experiment be so arranged as to allow air to enter along with and if the supply of air be limited while that of mercury is unlin air will be carried away, and a vacuum produced. The followi simplest form of the apparatus in which this action is realised. 136 *cd* is a glass tube longer than a barometer, open at both e connected by means of india-rubber tubing with a funnel, A, fi mercury and supported by a stand. Mercury is allowed to fa tube at a rate regulated by a clamp at *c*; the lower end of th fits in the flask B, which has a spout at the side a little higher lower end of *cd*; the upper part has a branch at *x* to which a R can be tightly fixed. When the clamp at *c* is opened, the firs

ury which runs out closes the tube and prevents air from en-
ielow. As the mercury is allowed to run down, the exhaus-
;ins, and the whole length
tube from *x* to *d* is filled
linders of air and mercury
a downward motion. Air
ercury escape through the
f the bulb B which is above
n A, where the mercury is
d. It is poured back from
time into the funnel A, to
ssed through the tube until
haustion is complete. As
int is approached, the en-
air between the mercury
rs is seen to diminish, until
er part of *cd* forms a con-
column of mercury about
es high. Towards this stage
process a noise is heard
at of a water hammer when
; the operation is com-
when the column of mercury
s no air, and a drop of mer-
lls on the top of the column
enclosing the slightest air
. The height of the column
presents the height of the
of mercury in the baro-
in other words, it is a baro-
whose Torricellian vacuum
receiver R. This apparatus
en used with great success
eriments in which a very
te exhaustion is required,
he preparation of Geissler's
(See Book X. Chapter VI.) It may be advantageously combined
exhausting syringe which first removes the greater part of the air,
austion being then completed as above.

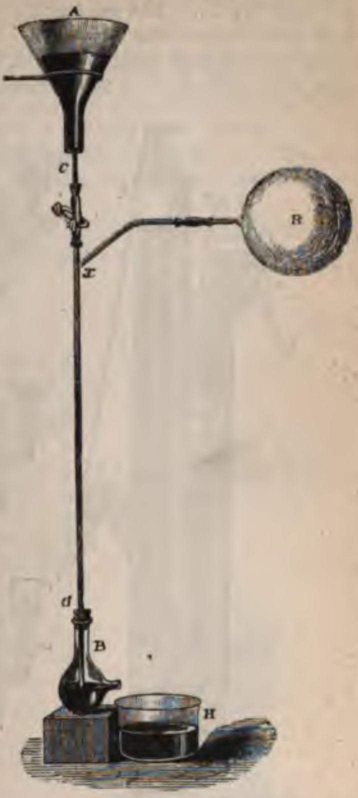


Fig. 136.

Morren's mercury pump.—Figs. 137 and 138 represent a mercu-
pump, which is an improvement by Alvergniat, of a form devised
rren.

nsists of two reservoirs, A and B, figs. 137 and 138, connected by a
ter tube T, and a long caoutchouc tube C. The reservoir B and
e T are fixed to a vertical support A, which is movable and open,
n be alternately raised and lowered through a distance of nearly
t. This is effected by means of a long wire rope, which is fixed at
l to the reservoir A, and passes over two pulleys, *a* and *b*, the latter

of which is turned by a handle. Above the reservoir B is a three cock *n*; to this is attached a tube *d*, for exhaustion, and on the left i ordinary stopcock *m*, which communicates with a reservoir of mercu and with the air. The exhausting tube *d* is not in direct communica with the receiver to be exhausted: it is first connected with a reservo partially filled with sulphuric acid, and designed to dry the gases wl enter the apparatus. A caoutchouc tube, *c*, makes communication

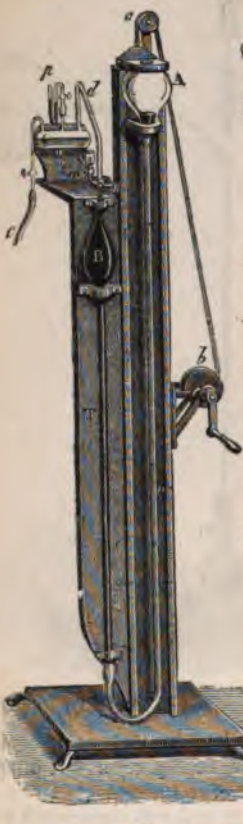
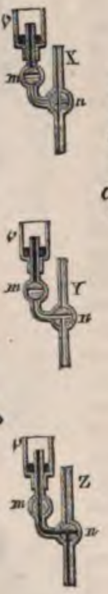


Fig. 137



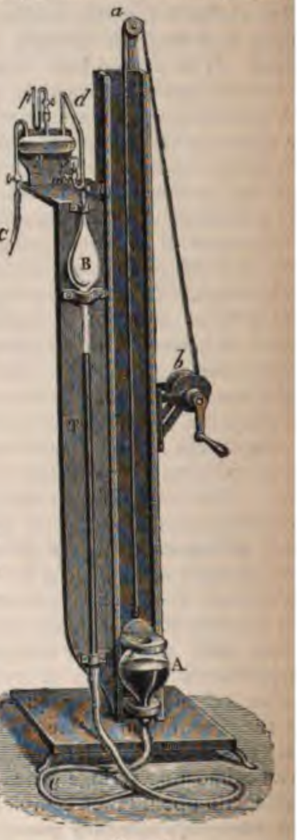


Fig. 138.

the receiver which is to be exhausted. On the reservoir *o* is a small cury manometer *p*.

These details being understood, suppose the reservoir A at the to its course (fig. 137), the stopcock *m* open, and the stopcock *n* turne seen in Z; the caoutchouc tube C, the tube T, the reservoir B, and tube above, are filled with mercury as far as *v*; closing then the stop *m*, and lowering the reservoir A (fig. 138), the mercury sinks in servoir B, and in the tube T, until the difference of levels in the two bes is equal to the barometric height, and there is a vacuum in the servoir B. Turning now the stopcok *n*, as shown in figure X, the s from the space to be exhausted passes into the barometric chamber , by the tubes *c* and *d*, and the level again sinks in the tube T. he stopcocks are now replaced in the first position (fig. Z), and the eservoir A is again lifted, the excess of pressure of mercury in the aoutchouc tube expels through the stopcocks, *n* and *m*, the gas which ad passed into the chamber B, and if a few droplets of mercury are arried along with them they are collected in the vessel *v*. The pro-cess is repeated until the mercury is virtually at the same level in both egs.

Like Sprengel's pump this is very slow in its working, and like it is best employed in completing the exhaustion of a space which has already been partially rarefied; for a vacuum of $\frac{1}{10}$th of a millimeter may be obtained by its means.

187. **Condensing pump.**—The condensing pump is an apparatus for compressing air, or any other gas. The form usually adopted is the following: In a cylinder, A, of small iameter (fig. 140), there is a solid iston, the rod of which is moved by he hand. The cylinder is provided ith a screw which fits into the receiver K. Fig. 139 shows the arrangement of the valves, which are so constructed that the lateral valve *o* opens rom the outside, and the lower valve from the inside.

When the piston descends, the alve *o* closes, and the elastic force f the compressed air opens the valve , which thus allows the compressed ir to pass into the receiver. When he piston ascends, *s* closes and *o* pens, and permits the entrance of esh air, which in turn becomes compressed by the descent of the piston, nd so on.

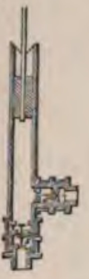


Fig. 139.

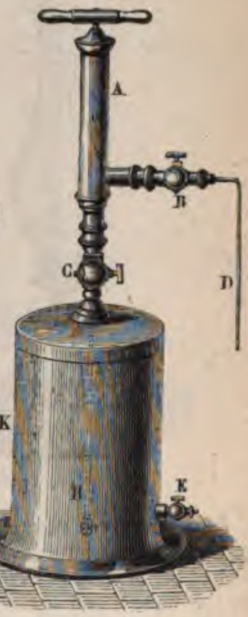


Fig. 140.

This apparatus is chiefly used for charging liquids with gases. For is purpose the stopcock B is connected with a reservoir of the gas, by eans of the tube D. The pump exhausts this gas, and forces it into e vessel K, in which the liquid is contained. The artificial gaseous ters are made by means of analogous apparatus.

188. **Uses of the air pump.**—A great many experiments with the air mp have been already described. Such are the mercurial rain (13), the

fall of bodies *in vacuo* (71), the bladder (142), the bursting of a bladder (148), the Magdeburg hemispheres (149), and the baroscope (176).

The *fountain in vacuo* (fig. 141) is an experiment made with the air pump, and shows the elastic force of the air. It consists of a glass globe, A, provided at the bottom with a stopcock, and a tubulure which projects into the interior. Having screwed this apparatus to the air pump it is exhausted, and, the stopcock being closed, it is placed in a vessel of water, R. Opening then the stopcock, the atmospheric pressure upon the water in the vessel makes it jet through the tubulure into the interior of the vessel as shown in the drawing.

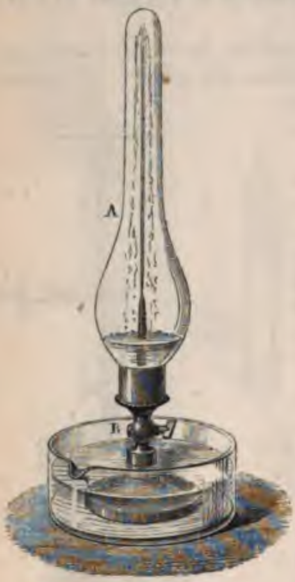


Fig. 141.

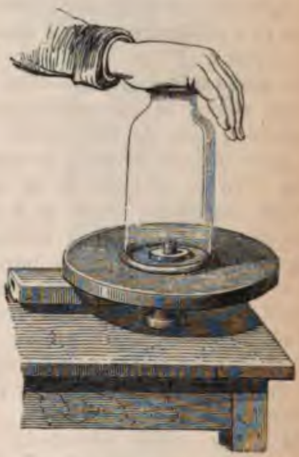


Fig. 142.

Fig. 142 represents an experiment illustrating the effect of atmospheric pressure on the human body. A glass vessel, open at both ends, being placed on the plate of the machine, the upper end of the cylinder is closed by the hands, and a vacuum is made. The hand then becomes pressed by the weight of the atmosphere, and can only be taken away by a great effort. And as the elasticity of the fluids contained in the organs is not counterbalanced by the weight of the atmosphere, the palm of the hand swells, and blood tends to escape from the pores.

By means of the air pump it may be shown that air, by reason of the oxygen it contains, is necessary for the support of combustion and of li For if we place a lighted taper under the receiver, and begin to exhau the air, the flame becomes weaker as rarefaction proceeds, and is final extinguished. Similarly an animal faints and dies, if a vacuum is form in a receiver under which it is placed. Mammalia and birds soon die *in vacuo*. Fish and reptiles support the loss of air for a much longer time. Insects can live several days *in vacuo*.

Substances liable to ferment may be kept *in vacuo* for a long time without alteration, as they are not in contact with oxygen, which is necessary for fermentation. Food kept in hermetically-closed cases, from which the air had been expelled, has been found as fresh after several years as on the first day.

189. **Hero's fountain.**—Hero's fountain, which derives its name from its inventor, Hero, who lived at Alexandria, 120 B.C., depends on the elasticity of the air. It consists of a brass dish, D (fig. 143), and of two glass globes, M and N. The dish communicates with the lower part of the globe N by a long tube, B; and another tube, A, connects the two globes. A third tube passes through the dish to the lower part of globe M. This tube having been taken out, the globe M is partially ed with water, the tube is then replaced, and water is poured into the h. The water flows through the tube B into the lower globe, and pels the air, which is forced into the upper globe; the air, thus com-ssed, acts upon the water, and makes it jet out as represented in the ure. If it were not for the resistance of the atmosphere and friction,

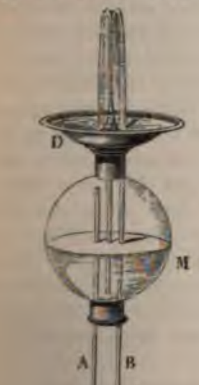


Fig. 143.

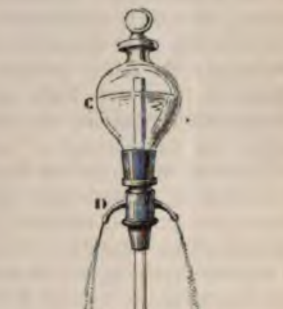


Fig. 144.

the liquid would rise to a height above the water in the dish eq
the difference of the level in the two globes.

190. **Intermittent fountain.**—The *intermittent fountain* d
partly on the elastic force of the air and partly on the atmospheri
sure. It consists of a stoppered glass globe (C, fig. 144), provide
two or three capillary tubulures, D. A glass tube open at bot
reaches at one end to the upper part of the globe C; the other e
minates just above a little aperture in the dish B, which suppo
whole apparatus.

The water with which the globe C is nearly two-thirds fille
out by the tubes D, as shown in the figure; the internal pressure
being equal to the atmospheric pressure, together with the weight
column of water CD, while the external pressure at that point i
that of the atmosphere. These conditions prevail so long as the
end of the glass tube is open, that is, so long as air can enter C an
the air in C at the same density as the external air; but the appar
arranged so that the orifice in the dish B does not allow so much
to flow out as it receives from the tubes D, in consequence of
the level gradually rises in the dish, and closes the lower end
glass tube. As the external air cannot now enter the globe C,
becomes rarefied in proportion as the flow continues, until the pr
of the column of water CD, together with the tension of t
contained in the globe, is equal to this external pressure at D: th
consequently stops. But as water continues to flow out of the di
tube D becomes open again, air enters, and the flow recommence
so on, as long as there is water in the globe C.

191. **The syphon.**—The syphon is a bent tube open at both end
with unequal legs (fig. 145). It is used in transferring liquids
following manner: The syphon is filled with some liquid, and t
ends being closed, the shorter leg is dipped in the liquid, as repre
in fig. 145; or the shorter leg having been dipped in the liquid,
is exhausted by applying the mouth at B. A vacuum is thus pro

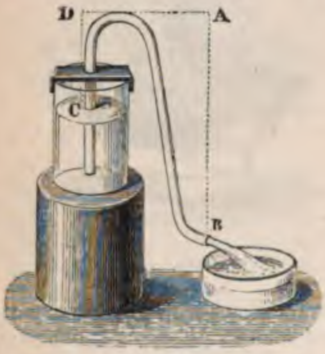


Fig. 145.

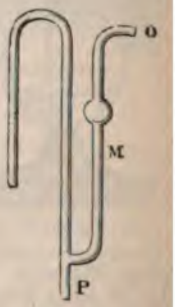


Fig. 146.

the liquid in C rises and fills the tube in consequence of the atmospheric pressure. It will then run out through the syphon as long as the shorter end dips in the liquid.

A syphon of the form represented in fig. 146 is used where the presence of the liquid in the mouth would be objectionable. A tube, M, is attached to the longer branch, and it is filled by closing the end P, and sucking at O. An enlargement, M, renders the passage of any liquid into the mouth more difficult.

To explain this flow of water from the syphon, let us suppose it filled and the short leg immersed in the liquid. The pressure then acting on C, and tending to raise the liquid in the tube, is the atmospheric pressure minus the height of the column of liquid DC. In like manner, the pressure on the end of the tube, B, is the weight of the atmosphere less the pressure of the column of liquid AB. But as this latter column is longer than CD, the force acting at B is less than the force acting at C, and consequently a flow takes place proportional to the difference between these two forces. The flow will therefore be more rapid in proportion as the difference of level between the aperture B and the surface of the liquid in C is greater.

It follows from the theory of the syphon that it would not work *in vacuo*, nor if the height CD were greater than that of a column of liquid which counterbalances the atmospheric pressure.

192. **The intermittent syphon.**—In the intermittent syphon the flow is not continuous. It is arranged in a vessel, so that the shorter leg is near the bottom of the vessel, while the longer leg passes through it (fig. 147). Being fed by a constant supply of water, the level gradually rises both in the vessel and in the tube to the top of the syphon, which it fills, and water begins to flow out. But the apparatus is arranged so that the flow of the syphon is more rapid than that of the tube which supplies the vessel, and consequently the level sinks in the vessel until the shorter branch no longer dips in the liquid; the syphon is then empty, and the flow ceases. But as the vessel is continually fed from the same source, the level again rises, and the same series of phenomena is reproduced.

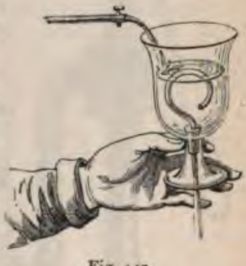


Fig. 147.

The theory of the intermittent syphon explains the natural intermittent springs which are found in many countries, and of which there is an excellent example near Giggleswick in Yorkshire. Many of these springs furnish water for several days or months, and then, after stopping for a certain interval, again recommence. In others the flow stops and recommences several times in an hour.

hese phenomena are explained by assuming that there are subter- an fountains, which are more or less slowly filled by springs, and h are then emptied by fissures so occurring in the ground as to form termittent syphon.

193. **Different kinds of pumps.**—*Pumps* are machines which s raise water either by suction, by pressure, or by both efforts com they are consequently divided into *suction or lift pumps*, *force pum suction and forcing pumps*.

The various parts entering into the construction of a pump barrel, the piston, the valves, and the pipes. The *barrel* is a cyli metal or of wood, in which is the piston. The latter is a metal or cylinder wrapped with tow, and working with gentle friction the length of the barrel.

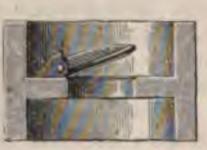


Fig. 148.

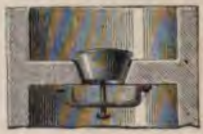


Fig. 149.

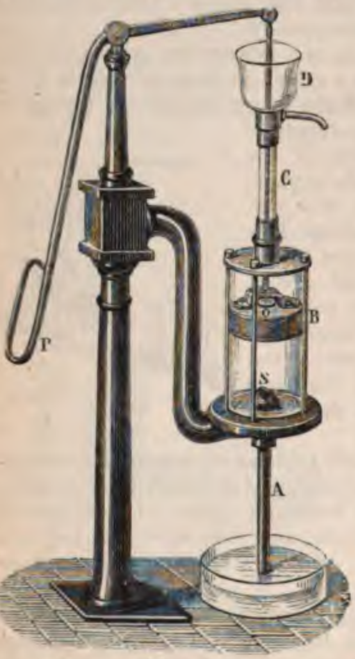


Fig. 150.

The valves are discs of metal or leather, which alternately cl apertures which connect the barrel with the pipes. The mos valves are the *clack valve* (fig. 148) and the *conical valve* (fig. 149) first is a metal disc fixed to on the edge of the orifice closed. In order more eff to close it, the lower part disc is covered with thick Sometimes the valve merely of a leather disc, o diameter than the orifice, n the edge of the orifice. I bility enables it to act as a

The conical valve consi metal cone fitting in an ap the same shape. Below th iron loop, through which p bolt-head fixed to the valv object of this is to limit t of the valve when it is ra the water, and to prevent moval.

194. **Suction pump.**—F represents a model of a pump such as is used in but which has the same ment as the pumps in com It consists, 1st, of a *glass* B, at the bottom of which a valve, S, opening upward of a *suction tube*, A, which dips into the reservoir from which

to be raised; 3rd, of a *piston*, which is moved up and down by a rod worked by a handle, P. The piston is perforated by a hole; the upper aperture is closed by a valve, O, opening upwards.

When the piston rises from the bottom of the cylinder, a vacuum is produced below, and the valve O is kept closed by the atmospheric pressure, while the air in the pipe A, in consequence of its elasticity, raises the valve S, and partially passes into the cylinder. The air being thus rarefied, water rises in the pipe until the pressure of the liquid column, together with the tension of the rarefied air which remains in the tube, counterbalances the pressure of the atmosphere on the water of the reservoir.

When the piston descends, the valve S closes by its own weight, and prevents the return of the air from the cylinder into the tube A. The air compressed by the piston opens the valve O, and escapes into the atmosphere by the pipe C. With a second stroke of the piston the same series of phenomena is produced, and after a few strokes the water reaches the cylinder. The effect is now somewhat modified; during the descent of the piston, the valve S closes, and the water raises the valve O, and passes above the piston, by which it is lifted into the upper reservoir D. There is now no more air in the pump, and the water, forced by the atmospheric pressure, rises with the piston, provided that when it is at the summit of its course it is not more than 34 feet above the level of the water in which the tube A dips, for we have seen (151) that a column of water of this height is equal to the pressure of the atmosphere.

In practice the height of the tube A does not often exceed 26 to 28 feet, for, although the atmospheric pressure can support a higher column, the vacuum produced in the barrel is not perfect, owing to the fact that the piston does not fit exactly on the bottom of the barrel. But when the water has passed the piston, it is the ascending force of the latter which raises it, and the height to which it can be brought depends on the force which moves the piston.

195. **Suction and force pump.**—The action of this pump, a model of which is represented in fig. 151, depends both on exhaustion and on pressure. At the base of the barrel, where it is connected with the tube A, there is a valve, S, which opens upwards. Another valve, O, opening in the same direction, closes the aperture of a conduit, which passes from a hole, *o*, near the valve S into a vessel, M, which is called the *air chamber*. From this chamber there is another tube, D, up which the water is forced.

At each ascent of the piston B, which is solid, the water rises through the tube A into the barrel. When the piston sinks, the valve S closes, and the water is forced through the valve O into the reservoir M, and from thence into the tube D. The height to which it can be raised in this tube depends solely on the motive force which works the pump.

If the tube D were a prolongation of the tube *Jao*, the flow would be intermittent; it would take place when the piston descended, and would cease as soon as it ascended. But between these tubes there is an interval, which, by means of the air in the reservoir M, ensures a continuous flow. The water forced into the reservoir M divides into two parts, one of which, rising in D, presses on the water in the reservoir by its weight; while the other, in virtue of this pressure, rises in the reservoir above the lower orifice of the tube D, compressing the air above. Consequently, when the piston ascends, and no longer forces the water into M, the air of the reservoir, by the pressure it has received, reacts on the liquid, and raises it in the tube D, until the piston again descends, so that the jet is continuous.

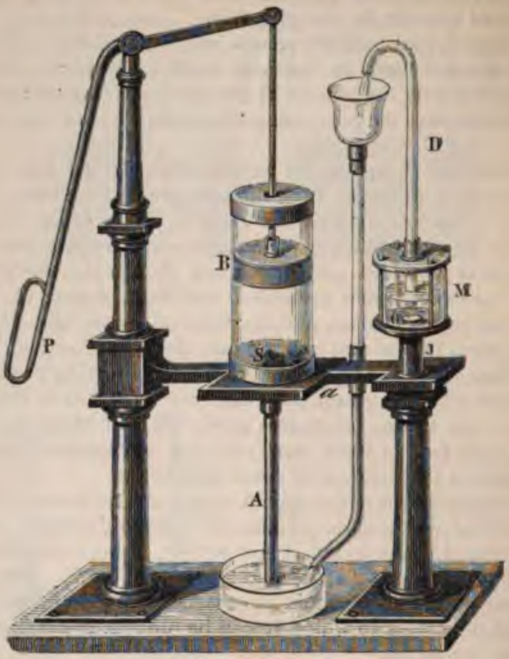


Fig. 151.

196. **Load which the piston supports.**—In the suction pump, when once the water fills the pipe and the barrel as far as the spout, *the effort necessary to raise the piston is equal to the weight of a column of water, the base of which is this piston, and the height the vertical distance of the spout from the level of the water in the reservoir, that is, the height to which the water is raised.* For if H is the atmospheric pressure, h the height of the water above the piston, and h' the height of the column which fills the suction tube A, and the lower part of the barrel, the pressure above the piston is obviously $H + h$, and that below is $H - h'$, since the weight of the column h' tends to counterbalance the atmospheric pressure. But the pressure $H - h'$ tending to raise the piston, the effec-

tive resistance is equal to the excess of $H+h$ over $H-h'$, that is to say, to $h+h'$, which is what was to be proved.

In the suction and force pump it is readily seen that the pressure which the piston supports is also equal to the weight of a column of water, the base of which is the section of the piston, and the height that to which the water is raised.

197. **Fire engine.**—The fire engine is a force pump in which a steady jet is obtained by the aid of an air chamber, and also by two pumps working alternately (fig. 152). The two pumps *m* and *n*, worked by the same lever PQ, are immersed in a tank, and which is kept filled with water as long as the pump works. From the arrangement of the valves it will be seen, that when one pump *n* draws water from the tank, the other *m* forces it into the *air chamber* R; whence, by an orifice Z, it passes into the delivery tube, by which it can be sent in any direction.

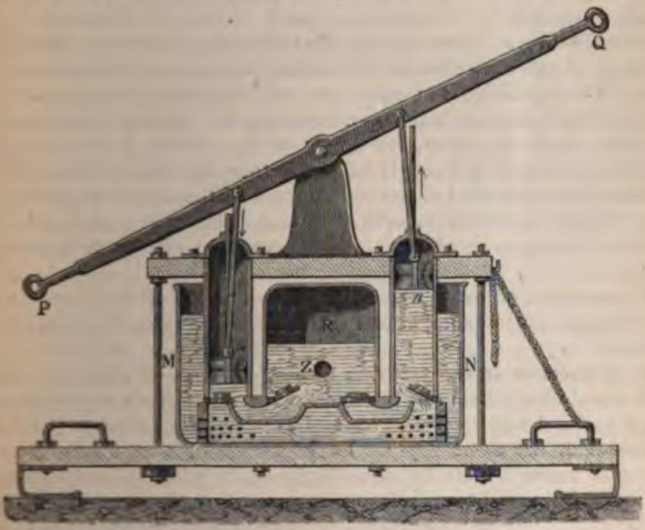


Fig. 152.

Without the air chamber the jet would be intermittent. For as the velocity of water on entering the reservoir is less than on emerging, the level of the water rises above the orifice Z, compressing the air which fills the reservoir. Hence, whenever the pistons stop, the air thus compressed reacting on the liquid forces it out during this momentary stoppage, and thus keeps up a constant flow.

198. **Velocity of efflux. Torricelli's theorem.**—Let us imagine an aperture made in the bottom of any vessel, and consider the case of a particle of liquid on the surface, without reference to those which are beneath. If this particle fell freely, it would have a velocity on reaching

the orifice equal to that of any other body falling through the distance between the level of the liquid and the orifice. This, from the laws of falling bodies, is $\sqrt{2gh}$, in which g is the accelerating force of gravity, and h the height. If the liquid be maintained at the same level, for instance, by a stream of water running into the vessel sufficient to replace what ha escaped, the particles will follow one another with the same velocity, and will issue in the form of a stream. Since pressure is transmitted equally in all directions, a liquid would issue from an orifice in the side with the same velocity, provided the depth were the same.

The law of the velocity of efflux was discovered by Torricelli. It may be enunciated as follows: *The velocity of efflux is the velocity which a freely falling body would have on reaching the orifice after having started from a state of rest at the surface.* It is algebraically expressed by the formula $v = \sqrt{2gh}$.

It follows directly from this law, that the velocity of efflux depends on the depth of the orifice below the surface, and not on the nature of the liquid. Through orifices of equal size and of the same depth, water and mercury would issue with the same velocity, for although the density of the latter liquid is greater, the weight of the column, and consequently the pressure, is greater too. It follows further that the velocities of efflux are directly proportional to the square roots of the depths of the orifices. Water would issue from an orifice 100 inches below the surface with ten times the velocity with which it would issue from one an inch below the surface.

The quantities of water which issue from orifices of different areas are very nearly proportional to the size of the orifice, provided the level remains constant.

199. **Direction of the jet from lateral orifices.**—From the principle of the equal transmission of pressure, water issues from an orifice in the side of a vessel with the same velocity as from an aperture in the bottom of a vessel at the same depth. Each particle of a jet issuing from the side of a vessel begins to move horizontally with the velocity above mentioned, but it is at once drawn downward by the force of gravity, in the same manner as a bullet fired from a gun, with its axis horizontal. It is well known that the bullet describes a parabola with a vertical axis, the vertex being the muzzle of the gun. Now since each particle of the jet moves in the same curve, the jet itself takes the parabolic form, as shown in fig 153.

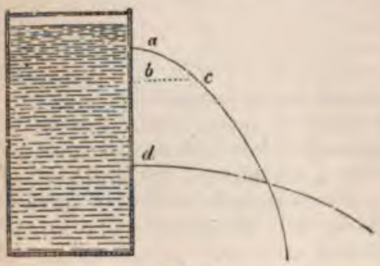


Fig. 153.

It may be remarked, that in every parabola there is a certain point called the focus, and that the distance from the vertex to the focus fixes the magnitude of a parabola in much the same manner as the istance from the centre to the circumference fixes the magnitude of a rcle. Now it is easily capable of proof that the focus is as much below, s the surface of the water is above, the orifice. Accordingly, the jets rmed by water coming from orifices at different depths below the rface take different forms, as shown in fig. 153.

200. **Height of the jet.**—If a jet issuing from an orifice in a vertical irection has the same velocity as a body would have which fell from the urface of the liquid to that orifice, the jet ought to rise to the level of the quid. It does not, however, reach this; for the particles which fall under it. But by inclining the jet at a small angle with the vertical, it eaches about $\frac{9}{10}$ths of the theoretical height, the difference being due to riction and to the resistance of the air. By experiments of this nature the truth of Torricelli's law has been demonstrated.

201. **Quantity of efflux. Vena contracta.**—If we suppose the sides of a vessel containing water to be thin, and the orifice to be a small circle whose area is A, we might think that the quantity of water E discharged in a second would be given by the expression $A\sqrt{2gh}$, since each particle has, on the average, a velocity equal to $\sqrt{2gh}$, and particles issue from each point of the orifice. But this is by no means the case. This may be explained by reference to fig. 154, in which AB represents an orifice in the bottom of a vessel—what is true in this case being equally true of an orifice in the side of the vessel. Every particle above AB endeavours to pass out of the vessel, and in so doing exerts a pressure on those near it. Those that issue near A and B exert pressures in the directions MM and NN; those near the centre of the orifice in the direction RQ, those in the intermediate parts in the directions PQ, PQ. In consequence, the water within the space PQP is unable to escape, and that which does escape, instead of assuming a cylindrical form, at first contracts, and takes the form of a truncated cone. It is found that the escaping jet continues to contract, until at a distance from the orifice about equal to the diameter of the orifice. This part of the jet is called the *vena contracta*. It is found that the area of its smallest section is about $\frac{5}{8}$ or 0·62 of that of the orifice. Accordingly, the true value of the efflux per second is given approximately by the formula

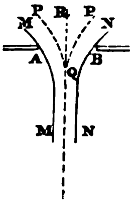


Fig. 154.

$$E = 0{\cdot}62A\sqrt{2gh}$$

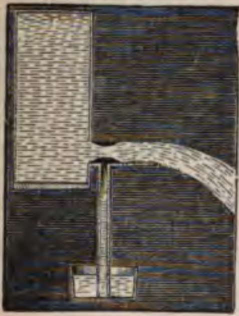
or the actual value of E is about 0·62 of its *theoretical amount.*

202. **Influence of tubes on the quantity of efflux.**—The result given in the last article has reference to an aperture in a thin wall. If a cylindrical or conical efflux-tube or *ajutage* is fitted to the aperture, the amount of the efflux is considerably increased, and in some cases falls but a little short of its theoretical amount.

A short cylindrical ajutage, whose length is from two to three times its diameter, has been found to increase the efflux per second to about $0{\cdot}82A\sqrt{2gh}$. In this case, the water on entering the ajutage forms a contracted vein (fig. 156), just as it would do on issuing freely into the air;

but afterwards it expands, and, in consequence of the adhesion of the water to the interior surface of the tube, has, on leaving the ajutage, a section greater than that of the contracted vein. The contraction of the jet within the ajutage causes a partial vacuum. If an aperture is made in the ajutage, near the point of greatest contraction, and fitted with a vertical tube, the other end of which dips into water (fig. 155), it is found that water rises in the vertical tube, thereby proving the formation of a partial vacuum.

Fig. 155.



If the ajutage has the form of a conic frustrum whose larger end is at the aperture, if the dimensions are properly chosen, the efflux in a second may be raised to $0{\cdot}92A\sqrt{2gh}$. If the smaller end of a frustrum of a cone of suitable dimensions be fitted to the orifice, the efflux may be still further increased, and fall very little short of the theoretical amount.

Fig. 156.

When the ajutage has more than a certain length, a considerable diminution takes place in the amount of the efflux: for example, if its length is 48 times its diameter, the efflux is reduced to $0{\cdot}63A\sqrt{2gh}$. This arises from the fact, that, when water passes along cylindrical tubes, the resistance increases with the length. This effect will be best understood by the following statement. If, in fig. 155, we suppose the ajutage to be replaced by a tube exceeding its diameter in length by a hundred times, at least, the efflux in a second E_1 will be related to that from the ajutage E as given above, in a manner approximately given by the formula $E_1 = E - 7{\cdot}376\sqrt{\frac{D}{L}}$, where D denotes the diameter of the tube and L its length: thus if the diameter were 1 inch, and the length 300 feet, the efflux in a second E_1 would be about one-eighth part of E. This result is true of water at ordinary temperatures. The resistance which gives rise to this result is called *hydraulic friction*; it is independent of the material of the tube, provided it be not roughened; but depends in a considerable degree on the viscosity of the liquid; for instance, ice-cold water experiences a greater resistance than lukewarm water.

203. **Form of the jet.**—After the contracted vein, the jet has the form of a solid rod for a short distance, but then begins to separate into drops which present a peculiar appearance. They seem to form a series of ventral and nodal segments (fig. 157). The ventral segments consist of drops extended in a horizontal direction, and the nodal segments in a longitudinal direction. And as the ventral and nodal segments have respectively a fixed position, each drop must alternately become elongated and flattened while it is falling (fig. 158). Between any two drops there are smaller ones, so tha tthe whole jet has a tube-like appearance.

f the aperture is not circular the form of the jet undergoes curious nges.

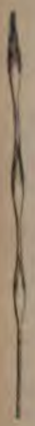


Fig. 157.

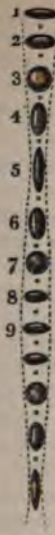


Fig. 158.

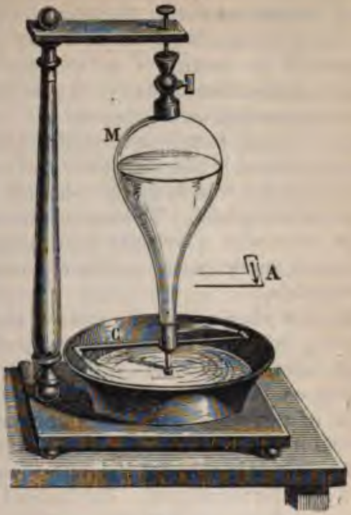


Fig. 159.

204. **Hydraulic tourniquet.**—If water be contained in a vessel, and an aperture made in one of the sides, the pressure at this point is removed, for it is expended in forcing out the water; but it remains on the other side; and if the vessel were movable in a horizontal direction, it would move in a direction opposite that of the issuing jet. This is illustrated by the apparatus known as the *hydraulic tourniquet*, or *Barker's mill* (fig. 159). It consists of a glass vessel, M, containing water, and capable of moving about its vertical axis. At the lower part there is a tube, C, bent horizontally in opposite directions at the two ends. If the vessel were full of water and the tubes closed, the pressures on the sides of C would balance each other, being equal and acting in contrary directions; but, being open, the water runs out, the pressure is not exerted on the open part, but only on the opposite side, as shown in the figure A. And this pressure, not being neutralised by an opposite pressure, imparts a rotatory motion in the direction of the arrow, the velocity of which increases with the height of the liquid and the size of the aperture.

The same principle may be illustrated by the following experiment. A tall cylinder containing water and provided with a lateral stopcock near the bottom is placed on a light shallow dish on water, so that it easily floats. On opening the stopcock so as to allow water to flow out, the vessel is observed to move in a direction diametrically opposite to that in which the water is issuing.

Segner's water-wheel and the reaction machine depend on this principle. Rotating fireworks also act on the same principle; that is, an unbalanced reaction from the heated gases which issue from openings in them gives them motion in the opposite direction.

205. **Water-wheels. Turbines.**—When water is continuously flowing from a higher to a lower level, it may be used as a motive power. This is effected by means of *water-wheels*; that is, wheels provided with buckets or float-boards at the circumference, and on which the water acts either by pressure or by impact.

Water-wheels turn in a vertical plane round a horizontal axis, and are of two principal kinds, *undershot* and *overshot*.

In *undershot* wheels the float-boards are at right angles to the circumference of the wheel. The lowest float-boards are immersed in the water, which flows with a velocity depending on the height of the fall. Such wheels are applicable where the quantity of water is great, but the fall inconsiderable.

Overshot wheels are used with a small quantity of water which has a high fall, as with small mountain streams. On the circumference of the wheel there are buckets of a peculiar shape. The water falls into the buckets on the upper part of the wheel, which is thus moved by the weight of the water, and as each bucket arrives at the lowest point of revolution it discharges all the water, and ascends empty.

The *turbine* is a horizontal water-wheel, and is similar in principle to the hydraulic tourniquet. But instead of the horizontal tubes there is a horizontal drum, containing curved vertical walls; the water, in issuing from the turbine, pressing against these walls, exerts a reaction, and turns the whole wheel about a vertical axis.

Turbines have the advantage of being of small bulk for their power, and equally efficient for the highest and the lowest falls.

In all prime movers worked by a fall of water, it is of the utmost importance to prevent the water from acting on the machine by impact, and thereby to prevent the great loss of power which is always occasioned by the impact of imperfectly elastic bodies.

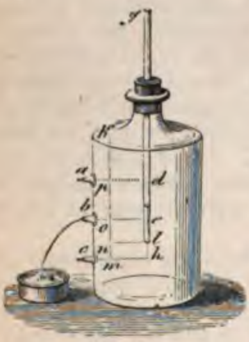


Fig. 160.

206. **Mariotte's bottle, its use.**—Mariotte's bottle presents many curious effects of the pressure of the atmosphere, and furnishes a means of obtaining a constant flow of water. It consists of a large narrow-mouth bottle, in the neck of which there is a tightly-fitting cork (fig. 160). Through this a tube passes, open at both ends. In the sides of the bottle there are three tubulures, each with a narrow orifice, and which can be closed at will.

The bottle and the tube being quite filled with water, let us consider what will be the effect of opening successively one of the tubulures, *a*, *b*, and *c*, supposing, as represented in the figure, that the lower extremity of *g* is between the tubulures *b* and *c*.

i. If the tubulure *b* is open the water flows out, and the surface sinks in the tube *g* until it is on the same level as *b*, when the flow stops. This flow arises from the excess of pressure at the point *e* over that at *b*. The pressure at *e* is the same as the pressure of the atmosphere. But when once the level is the same at *b* and at *e*, the efflux ceases, for the atmospheric pressure on all points of the same horizontal layer, *be*, is the same (93).

ii. If now the tubulure *b* is closed, and *a* opened, no efflux takes place; on the contrary, air enters by the orifice *a*, and water ascends in the tube *g*, as high as the layer *ad*, and then equilibrium is established.

iii. If the orifices *a* and *b* are closed, and *c* opened, an efflux having constant velocity takes place, as long as the level of the water is not below the open end, *l*, of the tube. Air enters bubble by bubble at *l*, and takes the place of the water which has flowed out.

In order to show that the efflux at the orifice *c* is constant, it is necessary to demonstrate that the pressure on the horizontal layer *ch* is always equal to that of the atmosphere in addition to the pressure of the column *hl*. Now suppose that the level of the water has sunk to the layer *ad*. The air which has penetrated into the flask supports a pressure equal to that of the atmosphere diminished by that of the column of liquid *pn*, or $H - pn$. In virtue of its elasticity this pressure is transmitted to the layer *ch*. But this layer further supports the weight of a column of water, *pm*, so that the pressure at *m* is really $pm + H - pn$, or $H + mn$, that is to say, $H + hl$.

In the same manner it may be shown that this pressure is the same when the level sinks to *b*, and so on as long as the level is higher than the aperture *l*. The pressure on the layer *ch* is therefore constant, and consequently the velocity of the efflux. But when once the level is below the point *l*, the pressure decreases, and with it the velocity.

To obtain a constant flow by means of Mariotte's bottle, it is filled with water, and the orifice which is below the tube *l* is opened. The rapidity of the flow is proportional to the square root of the height *hl*.

BOOK V.

ACOUSTICS.

CHAPTER I.

PRODUCTION, PROPAGATION, AND REFLECTION OF SOUND.

207. **Object of acoustics.**—The study of sounds, and that of the vibrations of elastic bodies, form the object of *acoustics*.

Music considers sounds with reference to the pleasurable feelings they are calculated to excite. Acoustics is concerned with the questions of the production, transmission, and comparison of sounds; to which may be added, the physiological question of the perception of sounds.

208. **Sound and noise.**—*Sound* is a peculiar sensation excited in the organ of hearing by the vibratory motion of bodies, when this motion is transmitted to the ear through an elastic medium.

All sounds are not identical; they present differences by which they may be distinguished, compared, and their relations determined.

Sounds are distinguished from *noises*. Sound properly so called, or *musical sound*, is that which produces a continuous sensation, and the musical value of which can be determined: while noise is either a sound of too short a duration to be determined, like the report of a cannon, or else it is a confused mixture of many discordant sounds, like the rolling of thunder or the noise of the waves. Nevertheless, the difference between sound and noise is by no means precise; Savart has shown that there are relations of height in the case of noise, as well as in that of sound; and there are said to be certain ears sufficiently well organised to determine the musical value of the sound produced by a carriage rolling on the pavement.

209. **Cause of sound.**—Sound is always the result of rapid oscillations imparted to the molecules of elastic bodies, when the state of equilibrium of these bodies has been disturbed either by a shock or friction. Such bodies tend to regain their first position of equilibrium, but only reach it after performing, on each side of that position, very rapid vibratory movements, the amplitude of which quickly decreases.

A body which produces a sound is called a *sonorous* body. As understood in England and Germany, a vibration comprises a motion to *and* fro; in France, on the contrary, a vibration means a movement to *or* fro. The French vibrations are with us semi-vibrations, an *oscillation* or *vi-*

is the movement of the vibrating molecule in only one direction : *e* or *complete vibration* comprises the oscillation both backwards wards. Vibrations are very readily observed. If a light powder kled on a body which is in the act of yielding a musical sound, a held horizontally in the hand, for example, a rapid motion is ed to the powder which renders visible the vibrations of the body; the same manner, if a stretched cord be smartly pulled and let go ations are apparent to the eye.

Sounds not propagated in vacuo.—The vibrations of elastic can only produce the sensation of sound in us by the intervention edium interposed between the ear and the sonorous body, and ng with it. This medium is usually the air, but all gases, vapours, , and solids also transmit sounds.

following experiment shows that the presence of a ponderable n is necessary for the propagation of sound. A small metallic bell, is continually struck by a small r by means of clockwork, or an y musical box, is placed under the r of the air-pump (fig. 161). As s the receiver is full of air at the y pressure, the sound is transbut in proportion as the air is ted the sound becomes feebler, and rceptible in a vacuum.

nsure the success of the experihe bellwork or musical box must ed on wadding; for otherwise the ons would be transmitted to the ough the plate of the machine.

Sound is propagated in all bodies.—If, in the above experifter the vacuum has been made, pour or gas be admitted, the sound bell will be heard, showing that s propagated in this medium as in

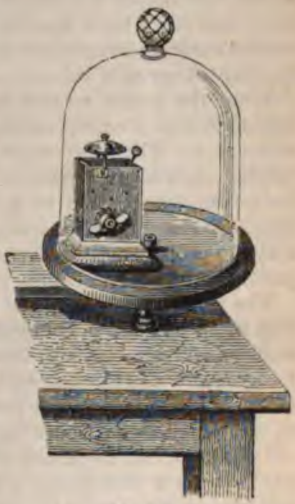


Fig. 161.

d is also propagated in liquids.

two bodies strike against each other under water, the shock is ly heard. And a diver at the bottom of the water can hear the f voices on the bank.

conductibility of solids is such, that the scratching of a pen at the a piece of wood is heard at the other end. The earth conducts o well, that at night, when the ear is applied to the ground, the horses or any other noise at great distances is heard.

Propagation of sound in the air.—In order to simplify the f the propagation of sound in the air, we shall first consider the which it is propagated in a cylindrical tube of indefinite length. N, fig. 162, be a tube filled with air at a constant pressure and temperature, and let P be a piston oscillating rapidly from A to *a*. When the piston passes from A to *a* it compresses the air in the tube. But in consequence of the great compressibility, the condensation of the air does not take place at once throughout the whole length of the tube, but solely within a certain length, *a*H, which is called the *condensed wave.*

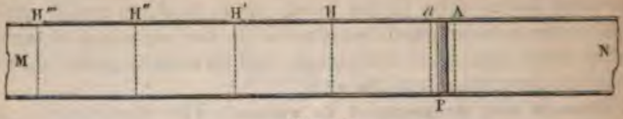


Fig. 162.

If the tube MN be supposed to be divided into lengths equal to *a*H and each of these lengths divided into layers parallel to the piston, it may be shown by calculation, that when the first layer of the wave *a*H comes to rest, the motion is communicated to the first layer of the second wave HH′, and so on from layer to layer in all parts of H′H″, H″H‴. The condensed wave advances in the tube, each of its parts having successively the same degrees of velocity and condensation.

When the piston returns in the direction *a*A, a vacuum is produced behind it, which causes an expansion of the air in contact with its posterior face. The next layer expanding in turn brings the first to its original state of condensation, and so on from layer to layer. Thus, when the piston has returned to A, an *expanded wave* is produced of the same length as the condensed wave, and directly following it in the tube where they are propagated together, the corresponding layers of the two waves possessing equal and contrary velocities.

The whole of a condensed and expanded wave forms an *undulation;* that is, an undulation comprehends that part of the column of air affected during the backward and forward motion of the piston. The *length of an undulation* is the space which sound traverses during a complete vibration of the body which produces it. This length is less in proportion as the vibrations are more rapid.

It is important to remark that if we consider a single row of particles, which when at rest occupy a line parallel to the axis of the cylinder, for instance, those along AH″ (fig. 162), we shall find they will have respectively at the same instant all the various velocities which the piston has had successively while oscillating from A to *a* and back to A. So that if in fig. 26 AH′ represents the length of one undulation, the curved line H′PQA will represent the various velocities which all the points in the line AH′ have *simultaneously*: for instance, at the instant the piston has returned to A, the particle at M will be moving to the right with a velocity represented by QM, the particle at N will be moving to the left with a velocity represented by PN, and so on of the other particles.

When an undulatory motion is transmitted through a medium, the motions of any two particles are said to be in the same *phase* when those particles move with equal velocities in the same direction; the motions are said to be in opposite phases when the particles move with the same velocities in opposite directions. It is plain, from an inspection of fig. 26, that when any two particles are separated by a distance equal to half an undulation, their motions are always in opposite phases, but if their distance equals the length of an undulation their motions are in the same phase.

A little consideration will show that in the *condensed wave* the condensation will be greatest at the middle of the wave, and likewise that the *expanded wave* will be most rarefied at its middle.

It is an easy transition from the theory of the motion of sonorous waves in a cylinder to that of their motions in an uninclosed medium. It is simply necessary to apply, in all directions, to each molecule of the vibrating body, what has been said about a piston movable in a tube. A series of spherical waves alternately condensed and rarefied is produced around each centre of disturbance. As these waves are contained within two concentrical spherical surfaces, whose radii gradually increase while the length of the undulation remains the same, their mass increases with the distance from the centre of disturbance, so that the amplitude of the vibration of the molecules gradually lessens, and the intensity of the sound diminishes.

It is these spherical waves, alternately condensed and expanded, which in being propagated transmit sound. If many points are disturbed at the same time, a system of waves is produced around each point. But all these waves are transmitted one through the other without modifying either their lengths or their velocities. Sometimes condensed or expanded waves coincide with others of the same nature to produce an effect equal to their sum; sometimes they meet and produce an effect equal to their difference. If the surface of still water be disturbed at two or more points, the co-existence of waves becomes sensible to the eye.

213. **Causes which influence the intensity of sound.**—Many causes modify the force or the *intensity* of the sound. These are, the distance of the sonorous body, the amplitude of the vibrations, the density of the air at the place where the sound is produced, the direction of the currents of air, and, lastly, the proximity of other sonorous bodies.

i. *The intensity of sound is inversely as the square of the distance of the sonorous body from the ear.* This law has been deduced by calculation, but it may be also demonstrated experimentally. Let us suppose several sounds of equal intensity—for instance, bells of the same kind, struck by hammers of the same weight, falling from equal heights. If four of these bells are placed at a distance of 20 yards from the ear, and one at a distance of 10 yards, it is found that the single bell produces a sound of the same intensity as the four bells struck simultaneously. Consequently, for double the distance the intensity of the sound is only one fourth.

The distance at which sounds can be heard depends on their intensity. The report of a volcano at St. Vincent was heard at Demerara, 300 miles off, and the firing at Waterloo was heard at Dover.

ii. *The intensity of the sound increases with the amplitude of the vibrations of the sonorous body.* The connection between the intensity of the sound and the amplitude of the vibrations is readily observed by means of vibrating cords. For if the cords are somewhat long, the oscilla perceptible to the eye, and it is seen that the sound is feebler i tion as the amplitude of the oscillations decreases.

iii. *The intensity of sound depends on the density of the air in in which it is produced.* As we have already seen (202), when a moved by clockwork is placed under the bell-jar of the air p sound becomes weaker in proportion as the air is rarefied.

In hydrogen, which is about $\frac{1}{14}$th the density of air, sounds a feebler, although the pressure is the same. In carbonic acid, on trary, whose density is 1·529, sounds are more intense. On hig tains, where the air is much rarefied, it is necessary to speak w effort in order to be heard, and the discharge of a gun produce feeble sound.

The ticking of a watch is heard in water at a distance of 23 fe of 16½, in alcohol of 13, and in air of only 10 feet.

iv. *The intensity of sound is modified by the motion of the at and the direction of the wind.* In calm weather sound is alwa propagated than when there is wind; in the latter case, for an e tance, sound is more intense in the direction of the wind than in trary direction.

v. Lastly, *sound is strengthened by the proximity of a sonorous* string made to vibrate in free air and not near a sounding body a very feeble sound; but when it vibrates above a sounding-b the case of the violin, guitar, or violoncello, its sound is mu intense. This arises from the fact that the box and the air whic tains vibrate in unison with the string. Hence the use of soundi in stringed instruments.

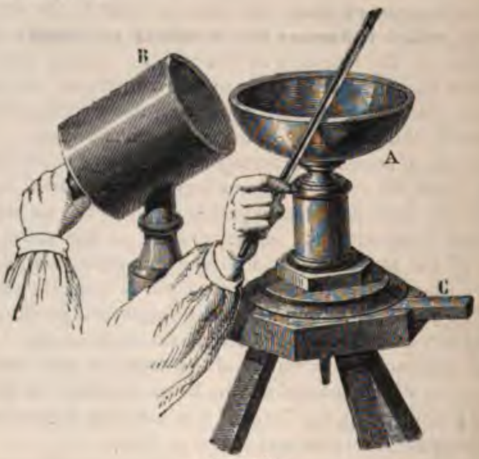


Fig. 163.

214. **Apparatus to strengthen sound.**—The apparatus repre fig. 163 was used by Savart to show the influence of boxes in stren

sound. It consists of a hemispherical brass vessel, A, which is set in vibration by means of a violin bow. Near it there is a hollow cardboard cylinder, B, closed at the further end. By means of a handle this cylinder can be turned on its support, so as to be inclined at any given degree towards the vessel. The cylinder is fixed on a slide, C, by which means it can be placed at any distance from A. When the vessel is made to vibrate, the strengthening of the sound is very remarkable. But the sound loses almost all its intensity if the cylinder is turned away, and it becomes gradually weaker when the cylinder is removed to a greater distance, showing that the strengthening is due to the vibration of the air in the cylinder.

The cylinder B is made to vibrate in unison with the brass vessel by adjusting it to a certain depth, which is effected by making one part slide into the other.

Vitruvius states that in the theatres of the ancients resonant brass vessels were placed to strengthen the voices of the actors.

215. **Influence of tubes on the transmission of sound.**—The law that the intensity of sound decreases in inverse proportion to the square of the distance does not apply to the case of tubes, especially if they are straight and cylindrical. The sonorous waves in that case are not propagated in the form of increasing concentrical spheres, and sound can be transmitted to a great distance without any perceptible alteration. M. Biot found that in one of the Paris water pipes, 1040 yards long, the voice lost so little of its intensity, that a conversation could be kept up at the ends of the tube in a very low tone. The weakening of sound becomes, however, perceptible in tubes of large diameter, or where the sides are rough. This property of transmitting sounds was first used in England for *speaking tubes.* They consist of caoutchouc tubes of small diameter passing from one room to another. If a person speaks at one end of the tube, he is distinctly heard by a person with his ear at the other end.

From M. Biot's experiments it is evident that a communication might be made between two towns by means of speaking tubes. The velocity of sound is 1125 feet in a second at 16·6 C., so that a distance of 50 miles would be traversed in four minutes.

216. **Velocity of sound in gases.**—Since the propagation of sonorous waves is gradual, sound requires a certain time for its transmission from one place to another, as is seen in numerous phenomena. For example, the sound of thunder is only heard some time after the flash of lightning has been seen, although both the sound and the light are produced simultaneously; and in like manner we see a mason in the act of striking a stone before hearing the sound.

The velocity of sound in air has often been the subject of experimental determination.

The most accurate of the direct measurements was made by Moll d Van Beck in 1823. Two hills, near Amsterdam, Kooltjesberg and enboomen, were chosen as stations; their distance from each other as termined trigonometrically was 57,971 feet, or nearly eleven miles. nnon were fired at stated intervals simultaneously at each station, and the time which elapsed between seeing the flash and hearing the sound was noted by chronometers. This time could be taken as that which the sound required to travel between the two stations; for it will be subsequently seen that light takes an inappreciable time to traverse the above distance. Introducing corrections for the barometric pressure, temperature and hygrometric state, and eliminating the influence of the wind, Moll and Van Beck's results as recalculated by Schröder van der Kolk give 1092·78 feet as the velocity of sound in one second in dry air and under a pressure of 760 mm.

The velocity of sound increases with the increase of temperature; it may be calculated for any temperature t° from the formula,

$$v = 1093\sqrt{1 + 0{\cdot}003665t}$$

where 1093 is the velocity at 0° C., and 0·003665 the coefficient of expansion for 1° C. This amounts to an increase of nearly two feet for every degree centigrade. For the same temperature it is independent of the density of the air, and consequently of the pressure. It is the same for the same temperature with all sounds, whether they be strong or weak, deep or acute. M. Biot found, in his experiments on the conductivity of sound in tubes, that when a well-known air was played on a flute at one end of a tube 1040 yards long, it was heard without alteration at the other end, from which he concluded that the velocity of different sounds is the same. For the same reason the tune played by a band is heard at a great distance without alteration, except in intensity, which could not be the case if some sounds travelled more rapidly than others.

This cannot, however, be admitted as universally true. Earnshaw, by a profound mathematical investigation of the laws of the propagation of sound, has found that the velocity of a sound depends on its strength; and, accordingly, that a violent sound ought to be propagated with greater velocity than a gentler one. This conclusion is confirmed by an observation made by Captain Parry on his Arctic expedition. During artillery practice it was found, by persons stationed at a considerable distance from the guns, that the report of the cannon was heard before the command of fire given by the officer. And more recently, Mallet made a series of experiments on the velocity with which sound is propagated in rocks, by observing the times which elapsed before blastings made at Holyhead were heard at a distance. He found that the larger the charge of gunpowder, and therefore the louder the report, the more rapid was the transmission. With a charge of 2000 pounds of gunpowder the velocity was 967 feet in a second, while with a charge of 12,000 it was 1210 feet in the same time.

MM. Bravais and Martins found, in 1844, that sound travelled with the same velocity from the base to the summit of the Faulhorn as from the summit to the base.

Mallet has investigated the velocity of the transmission of sound in various rocks, and finds that it is as follows:

Wet sand	825	ft. in a second.
Contorted, stratified quartz and slate rock .	1088	„
Discontinuous granite	1306	„
Solid granite	1664	„

217. **Formulæ for calculating the velocity of sound in gases.**—For calculating the velocity of sound in gases Newton gave a rule equivalent to the formula

$$v=\sqrt{\frac{e}{d}}$$

in which v represents the velocity of the sound or the distance it travels in a second, e the elasticity of the gas, and d its density.

This formula expresses that the velocity of the propagation of sound in gases *is directly as the square root of the elasticity of the gas, and inversely as the square root of its density.* It follows that the velocity of sound is the same under any pressure, for although the elasticity increases with greater pressure, the density increases in the same ratio. At Quito, where the mean pressure is only 21·8 inches, the velocity is the same as at the sea level, provided the temperature is the same.

If g be the force of gravity, h the barometric height reduced to the temperature zero, and δ the density of mercury, also at zero, it is clear that for a gas under the atmospheric pressure, and for zero, $e=gh\delta$; Newton's formula then becomes

$$v=\sqrt{\frac{gh\delta}{d}}$$

Now if we suppose the temperature of a gas to increase from 0° to $t°$, its volume will increase from unity at zero to $1+a\,t$ at t, a being the coefficient of expansion of the gas. But the density varies inversely as the volume, therefore d becomes $d\div(1+at)$. Hence

$$v=\sqrt{\frac{gh}{d}(1+at)}$$

The values of v, obtained by this formula, are less than the experimental results. Laplace assigned as a reason for this discrepancy the heat produced by pressure in the condensed waves; and, by considerations based on this idea, Poisson and Biot have found that Newton's formula ought to be written $v=\sqrt{\frac{gh\delta}{d}(1+at)\frac{c}{c'}}$; c being the specific heat of the gas for a constant pressure, and c' its specific heat for a constant volume (see Book VI.). When thus modified the results calculated by the formula agree with the experimental results.

The physical reason for introducing the constant $\frac{c}{c'}$ into the equation for the velocity of sound may be understood from the following considerations. We have already seen that sound is propagated in air by a series of alternate condensations and rarefactions of the layers. At each condensation heat is evolved, and this heat increases the elasticity, and thus the rapidity, with which each condensed layer acts on the next; but, on the rarefaction of each layer, the same amount of heat disappears as was developed by the condensation, and its elasticity is diminished by the cooling. The effect of this diminished elasticity of the cooled layer is the same as if the elasticity of an adjacent wave had been increased, a the rapidity with which this latter would expand upon the dilated wa would be greater. Thus, while the average temperature of the air unaltered, both the heating which increases the elasticity and the chilli which diminishes it concur in increasing velocity.

Knowing the velocity of sound, we can calculate approximately t distance at which it is produced. Light travels with such velocity th the flash or the smoke accompanying the report of a gun may be co sidered to be seen simultaneously with the explosion. Counting the the number of seconds which elapse between seeing the flash and hea ing the sound, and multiplying this number by 1125, we get the distanc in feet at which the gun is discharged. In the same way the distance thunder may be estimated.

218. **Velocity of sound in various gases.**—Approximately the sa results have been obtained for the velocity of sound in air, by anoth method by which the velocity in other gases could be determined. A the wave length λ, is the distance which sound travels during the time one oscillation, that is n of a second, the velocity of sound or the distanc traversed in a second is $v = n\lambda$. Now the length of an open pipe i half the wave length of the fundamental note of that pipe; and that c a closed pipe is a quarter of the wave length. Hence if we know th number of vibrations of the note emitted by any particular pipe, whic can be easily ascertained by means of the syren, and we know th length of this pipe, we can calculate v. Taking the temperature int account, Wertheim found 1086 feet for the velocity of sound at zero.

Further, since in different gases which have the same elasticity, bu differ in density, the velocity of sound varies inversely as the squar root of the density, knowing the velocity of sound in air, we may calculat it for other gases ; thus, in hydrogen it will be

$$\frac{1093}{\sqrt{0{\cdot}0688}} = 4168 \text{ feet}$$

This number cannot be quite accurate, for the coefficient $\frac{c}{c_1}$ differs somewhat in different gases. And when pipes were sounded with different gases, and the number of vibrations of the notes multiplied with twice the length of the pipe, numbers were obtained which differed from those calculated by the above method. When, however, the calculation was made, introducing for each gas the special value of $\frac{c}{c_1}$, the theoretical results agreed very well with the observed ones.

By the above method the following values have been obtained :—

Carbonic acid	856	ft. in a secon
Oxygen	1040	,,
Air	1093	,,
Carbonic oxide	1106	,,
Hydrogen	4163	,,

219. **Doppler's principle.**—When a sounding body approaches the ear, the tone perceived is somewhat higher than the true one; but if the source of sound recedes from the ear, the tone perceived is lower. The truth of this, which is known as *Doppler's principle*, will be apparent from the following considerations:—When the source of sound and the ear are at rest, the air perceives n waves in a second; but if the ear approaches the sound (or *vice versâ*) it perceives more; just as a ship meets more waves when it ploughs through them than if it is at rest. Conversely, the ear receives a smaller number when it recedes from the source of sound. The effect in the first case is as if the sounding body emitted more vibrations in a second than it really does, and in the second case fewer. Hence in the first case the note appears higher; in the second case lower.

If the distance which the ear traverses in a second towards the source of sound (supposed stationary) is s feet and the wave length of the particular tone is λ feet, then there are $\frac{s}{\lambda}$ waves in a second; or also $\frac{ns}{c}$ for $\lambda = \frac{c}{n}$, where c is the velocity of sound (216). Hence the ear receives not only the n original waves, but also $\frac{ns}{c}$ in addition. Therefore, the number of vibrations which the ear actually perceives is

$$n' = n + \frac{ns}{c} = n\left(1 + \frac{s}{c}\right)$$

for an ear which approaches a tone; and by similar reasoning it is

$$n' = n - \frac{ns}{c} = n\left(1 - \frac{s}{c}\right)$$

for an ear receding from a tone.

To test Doppler's theory Buys Ballot stationed trumpeters on the Utrecht Railway, and also upon locomotives, and had the height of the approaching or receding tones compared with stationary ones by musicians. He thus found both the principle and the formula fully confirmed.

220. **Velocity of sound in liquids and in solids.**—The velocity of sound in water was investigated in 1827 by Colladon and Sturm. They moored two boats at a known distance in the Lake of Geneva. The first supported a bell immersed in water, and a bent lever provided at one end with a hammer which struck the bell, and at the other with a lighted wick, so arranged that it ignited some powder the moment the hammer struck the bell. To the second boat was affixed an ear-trumpet, the bell of which was in water, while the mouth was applied to the ear of the observer, so that he could measure the time between the flash of light and the arrival of sound by the water. By this method the velocity was found to be 4708 feet in a second at the temperature 8·1°, or four times as great as in air.

The velocity of sound, which is different in different liquids, can be calculated by a formula analogous to that *given above* (217) as applicable to gases. In this way are obtained the number given in the following table. As in the case of gases, the velocity varies with the temperature which is therefore appended in each case :—

River water (Seine) . . .	13°C.	= 4714 ft. in a second.
" " " . . .	30	= 5013 "
Artificial sea-water . . .	20	= 4761 "
Solution of common salt . .	18	= 5132 "
" " chloride of calcium .	23	= 6493 "
Absolute alcohol	23	= 3804 "
Turpentine	24	= 3976 "
Ether		= 3801 "

As a general rule, this elasticity of solids, as compared with the density is greater than that of liquids, and consequently the propagation of soun is more rapid.

The difference is well seen in an experiment by M. Biot, who found that when a bell was struck by a hammer, at one end of an iron tub 3120 feet long, two sounds were distinctly heard at the other end. Th first of these was transmitted by the tube itself with a velocity x; and th second by the enclosed air with a known velocity a. The interval betwee the sounds was 2·5 seconds. The value of x obtained from the equation

$$\frac{3120}{a} - \frac{3120}{x} = 2 \cdot 5$$

shows that the velocity of sound in the tube is between 9 and 10 times as great as that in air.

To this class of phenomena belongs the fact that if the ear is held against a rock in which a blasting is being made at a distance, two distinct reports are heard, one transmitted through the rock to the ear, and the other transmitted through the air.

The velocity of sound in other solids has also been determined theoretically by Wertheim, by means of their coefficient of elasticity.

The following table gives the velocity, expressed in feet per second :—

Lead	4030	Pine	10900
Gold	5717	Oak	12622
Silver.	8553	Ash	13314
Copper	11666	Elm	13516
Steel wire	15470	Fir	15218
Iron	16822	Aspen	16677

The velocity in the direction of the fibres was greater than across them.

221. **Reflection of sound.**—So long as sonorous waves are not obstructed in their motion, they are propagated in the form of concentric spheres ; but, when they meet with an obstacle, they follow the general law of elastic bodies ; that is, they return upon themselves, forming new concentric waves, which seem to emanate from a second centre on the other side of the obstacle. This phenomenon constitutes the reflectio of sound.

Fig. 164 represents a series of incident waves reflected from an obstacle, PQ. Taking, for example, the incident wave MCDN, emitted from

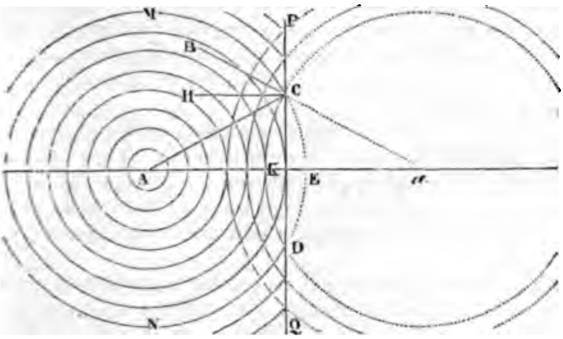


Fig. 164.

the centre A, the corresponding reflected wave is represented by the arc, CKD, of a circle, whose centre *a* is as far beyond the obstacle PQ as A is before it.

If any point, C, of the reflecting surface be joined to the sonorous centre, and if the perpendicular CH be let fall on the surface of this body, the angle ACH is called the *angle of incidence*, and the angle BCH, formed by the prolongation of *a*C, is the *angle of reflection.*

The reflection of sound is subject to the two following laws :—

I. *The angle of reflection is equal to the angle of incidence.*

II. *The incident sonorous ray and the reflected ray are in the same plane perpendicular to the reflecting surface.*

From these laws it follows that the wave which in the figure is propagated in the direction AC, takes the direction CB after reflection, so that an observer placed at B hears, besides the sound proceeding from the point A, a second sound, which appears to come from C.

The laws of the reflection of sound are the same as those for light and radiant heat, and may be demonstrated by similar experiments. One of the simplest of these is made with conjugate mirrors (see chapter on Radiant Heat) : if in the focus of one of these mirrors a watch is placed, the ear placed in the focus of the second mirror hears the ticking very distinctly, even when the mirrors are at a distance of 12 or 13 yards.

222. **Echoes and resonances.**—An *echo* is the repetition of a sound in the air, caused by its reflection from some obstacle.

A very sharp quick sound can produce an echo when the reflecting surface is 55 feet distant, but for articulate sounds at least double that distance is necessary, for it may be easily shown that no one can pronounce or hear distinctly more than five syllables in a second. Now, as the velocity of sound at ordinary temperatures may be taken at 1125 feet in a second, in a fifth of that time sound would travel 225 feet. If the reflecting surface is 112·5 feet distant in going and returning, sound would travel through 225 feet. The time which elapses between the articulated and the reflected sound would, therefore, be a fifth of a second, th two sounds would not interfere, and the reflected sound would be distinctly heard. A person speaking with a loud voice in front of a reflecto at a distance of 112·5 feet, can only distinguish the last reflected syllable such an echo is said to be *monosyllabic*. If the reflector were at a distance of two or three times 112·5 feet, the echo would be *dissyllabi* *trisyllabic*, and so on.

When the distance of the reflecting surface is less than 112·5 feet, the direct and the reflected sound are confounded. They cannot be heard separately, but the sound is strengthened. This is what is called *resonance*, and is often observed in large rooms. Bare walls are very resonant; but tapestry and hangings, which are bad reflectors, deaden the sound.

Multiple echoes are those which repeat the same sound several times: this is the case when two opposite surfaces (for example, two parallel walls) successively reflect sound. There are echoes which repeat the same sound 20 or 30 times. An echo in the château of Simonetta, in Italy, repeats a sound 30 times. At Woodstock there is one which repeats from 17 to 20 syllables.

As the laws of reflection of sound are the same as those of light and heat, curved surfaces produce *acoustic foci* like the luminous and calorific foci produced by concave reflectors. If a person standing under the arch of a bridge speaks with his face turned towards one of the piers, the sound is reproduced near the other pier with such distinctness that a conversation can be kept up in a low tone, which is not heard by any one standing in the intermediate spaces.

There is a square room with an elliptical ceiling, on the ground floor of the Conservatoire des Arts et Métiers, in Paris, which presents this phenomenon in a remarkable degree when persons stand in the two foci of the ellipse.

It is not merely by solid surfaces, such as walls, rocks, etc., that sound is reflected. It is also reflected by clouds, and on passing into a layer of air of greater density than its own; it is also further reflected by the vesicles of mist. When the weather is foggy, sounds undergo innumerable partial reflections, and are rapidly destroyed.

Whispering galleries are formed of smooth walls having a continuous curved form. The mouth of the speaker is presented at one point, and the ear of the hearer at another and distant point. In this case, the sound is successively reflected from one point to the other until it reaches the ear.

Different parts of the earth's surface are unequally heated by the sun, owing to the shadows of trees, evaporation of water, and other causes, so that in the atmosphere there are numerous ascending and descending currents of air of different density. Whenever a sonorous wave passes from a medium of one density into another it undergoes partial reflection, which, though not strong enough to form an echo, distinctly weakens the direct sound. This is doubtless the reason, as Humboldt remarks, why sound travels further at night than at daytime; even in the South

American forests, where the animals, which are silent by day, fill the atmosphere in the night with thousands of confused sounds.

223. **Refraction of sound.**—It will be found in the sequel that *refraction* is the change of direction which light and heat experience on passing from one medium to another. Sondhauss has found that sonorous waves are refracted like light and heat. He constructed gas lenses, by filling spherical or lenticular collodion envelopes with carbonic acid. With envelopes of paper or of goldbeater's-skin the refraction of sound is not perceptible.

Sondhauss cut equal segments out of a large collodion balloon, and fastened them on the two sides of a sheet iron ring a foot in diameter, so as to form a hollow biconvex lens about 4 inches thick in the centre. This was filled with carbonic acid, and a watch was placed in the direction of the axis : the point was then sought, on the other side of the lens, at which the sound was most distinctly heard. It was found that when the ear was removed from the axis, the sound was scarcely perceptible ; but that at a certain point on the axial line it was very distinctly heard. Consequently, the sonorous waves in passing from the lens had converged towards the axis, their direction had been changed ; in other words, they had been refracted.

The refraction of sound may be easily demonstrated by means of one of the very thin india-rubber balloons used as children's toys, inflated by carbonic acid. If the balloon be filled with hydrogen, no focus is detected ; it acts like a convex lens, and the divergence of the rays is increased instead of their being converged to the ear.

224. **Speaking trumpet. Ear trumpet.**—These instruments are based both on the reflection of sound and on its conductibility in tubes.

The *speaking trumpet*, as its name implies, is used to render the voice audible at great distances. It consists of a slightly conical tin or brass ube (fig. 165), very much wider at one end (which is called the *bell*), and rovided with a mouthpiece at the other. The larger the dimensions of his instrument the greater is the distance at which the voice is heard. ts action is usually ascribed to the successive reflections of sonorous aves from the sides of the tube, by which the waves tend more and ore to pass in a direction parallel to the axis of the instrument. It has, wever, been objected to this explanation, that the sounds emitted by e speaking trumpet are not stronger solely in the direction of the axis, t in all directions, that the bell would not tend to produce parallelism the sonorous wave, whereas it certainly exerts considerable influence strengthening the sound. No satisfactory explanation has been given he effect of the bell.

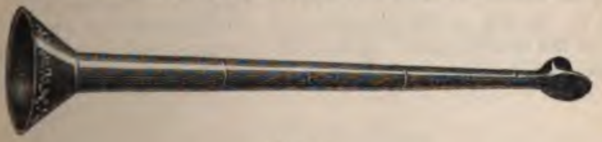


Fig. 165.

The *ear trumpet* is used by persons who are hard of hearing. It essentially an inverted speaking trumpet, and consists of a conical metal tube, one of whose extremities, terminating in a *bell*, receives the soun while the other end is introduced into the ear. This instrument is t reverse of the speaking trumpet. The bell serves as a mouthpiece ; th is, it receives the sound coming from the mouth of the person wl speaks. These sounds are transmitted by a series of reflections to t interior of the trumpet, so that the waves, which would become great developed, are concentrated on the auditory apparatus, and produce a f greater effect than divergent waves would have done.

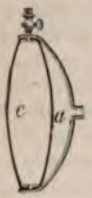


Fig. 166.

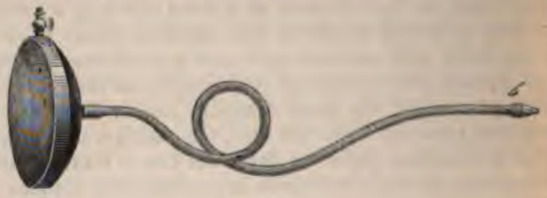


Fig. 167.

225. **Stethoscope.**—One of the most useful applications of acousti principles is the stethoscope. Figs. 166, 167 represent an improved fo of this instrument devised by König. Two sheets of caoutchouc, *c* and are fixed to the circular edge of a hollow metal hemisphere ; the edge provided with a stopcock, so that the plates can be inflated, and th present the appearance of a double convex lens as represented in secti in fig. 166. To a tubulure on the hemisphere is fixed a caoutchouc tu terminated by horn or ivory, *o*, which is placed in the ear (fig. 167).

When the membrane of the stethoscope is applied to the chest of a si person, the beating of the heart and the sounds of respiration are tran mitted to the air in the chamber CA, and from thence to the ear l means of the flexible tube. If several tubes are fixed to the instrume as many observers may simultaneously auscultate the same patient.

CHAPTER II.

MEASUREMENT OF THE NUMBER OF VIBRATIONS.

226. **Savart's apparatus.**—*Savart's toothed wheel*, so called from t name of its inventor, is an apparatus by which the absolute number vibrations corresponding to a given note can be determined. It cons of a solid oak frame in which there are two wheels, A and B (fig. 16 the larger wheel, A, is connected with the toothed wheel by means o strap and a multiplying wheel, thereby causing the toothed whee revolve with great velocity ; a card, E, is fixed on the frame, and revolving, the toothed wheel strikes against it, and causes it to vibr

The card being struck by each tooth, makes as many vibrations as there are teeth. At the side of the apparatus there is an indicator, H, which gives the number of revolutions of the wheel, and consequently the number of vibrations in a given time.

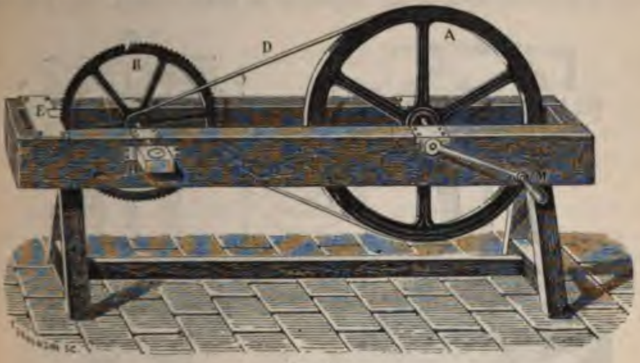


Fig. 168.

When the wheel is moved slowly, the separate shocks against the card are distinctly heard; but, if the velocity is gradually increased, the sound becomes higher and higher. Having obtained the sound whose number of vibrations is to be determined, the revolution of the wheel is continued with the same velocity for a certain number of seconds. The number of turns of the toothed wheel B is then read off on the indicator, and this multiplied by the number of teeth in the wheel gives the total number of vibrations. Dividing this by the corresponding number of seconds, the quotient gives the number of vibrations per second for the given sound.

227. **Syren.**—The *syren* is an apparatus which, like Savart's wheel, is used to measure the number of vibrations of a body in a given time. The name 'syren' was given to it by its inventor, Cagniard Latour, because it yields sound under water.

It is made entirely of brass. Fig. 169 represents it fixed on the table of a bellows, by which a continuous current of air can be sent through it. Figs. 170 and 171 show the internal details. The lower part consists of a cylindrical box, O, closed by a fixed plate, B. On this plate a vertical rod, T, rests, to which is fixed a disc, A, moving with the rod. In the plate B there are equidistant circular holes, and in the disc A are an equal number of holes of the same size, and the same distance from the centre as those of the plate. These holes are not perpendicular to the disc; they are all inclined to the same extent in the same direction in the plate, and are inclined to the same extent in the opposite direction in the disc, so that when they are opposite each other they have the appearance represented in *mn*, fig. 171. Consequently, when a current of air from the bellows reaches the hole *m*, it strikes obliquely against the sides of the hole *n*, and imparts to the disc A a rotatory motion in the direction *n*A.

For the sake of simplicity, let us first suppose that in the movable disc A there are eighteen holes, and in the fixed plate B only one, which faces one of the upper holes.—The wind from the bellows striking against the sides of the latter, the movable disc begins to rotate, and the space between two of its consecutive holes closes the hole in the lower plate. But as the disc continues to turn from its acquired velocity, two holes are again opposite each other, a new impulse is produced, and so on. During a complete revolution of the disc the lower hole is eighteen times open and eighteen times closed. A series of effluxes and stoppages is thus produced, which makes the air vibrate, and ultimately produces a sound when the successive impulses are sufficiently rapid. If the fixed plate, like the moving disc, had eighteen holes, each hole would separately produce the same effect as a separate one, the sound would be eighteen times as intense, but the number of vibrations would not be increased.

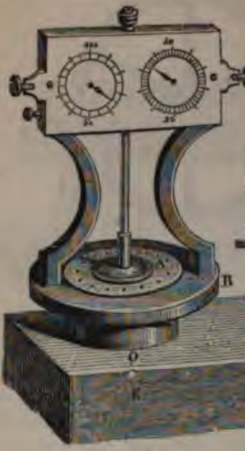
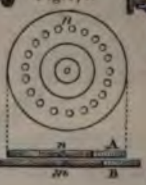


Fig. 169.

Fig. 171.



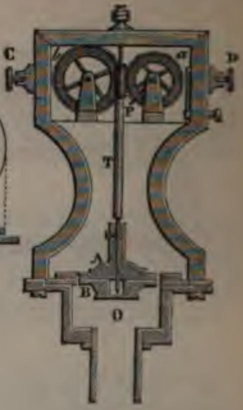


Fig. 170.

In order to know the number of vibrations corresponding to the sound produced, it is necessary to know the number of revolutions of the disc A in a second. For this purpose an endless screw on the rod T transmits the motion to a wheel, *a*, with 100 teeth. On this wheel, which moves by one tooth for every turn of the disc, there is a catch, P, which at each complete revolution moves one tooth of a second wheel, *b* (fig. 170). On the axis of these wheels there are two needles, which move round dials represented in fig. 169. One of these indices gives the number of turns of the disc A, the other the number of hundreds of turns. By means of two screws, D and C, the wheel *a* can be uncoupled from the endless screw.

Since the sound rises in proportion to the velocity of the disc A, the wind is forced until the desired sound is produced. The same current is kept up for a certain time, two minutes for example, and the number of turns read off. This number multiplied by 18, and divided by 120, indicates the number of vibrations in a second.

With the same velocity the syren gives the same sound in air as in water; the same is the case with all gases; and it appears, therefore, that any given sound depends on the number of vibrations, and not on the nature of the sounding body.

The buzzing and humming noise of certain insects is not vocal, but is produced by very rapid flapping of the wings against the air or the body. The syren has been ingeniously applied to count the velocity of the undulations thus produced, which is effected by bringing it into unison with the sound. It has thus been found that the wings of a gnat flap at the rate of 15,000 times in a second.

228. **Bellows.**—In acoustics a *bellows* is an apparatus by which wind instruments, such as the syren and organ pipes, are worked. Between the four legs of a table there is a pair of bellows, S (fig. 172), which is worked by means of a pedal, P. D is a reservoir of flexible leather, in which is stored the air forced in by the bellows. If this reservoir is pressed by means of weights on a rod, T, moved by the hand, the air is driven through a pipe, E, into a chest, C, fixed on the table. In this chest there are small holes closed by leather valves, which can be opened by pressing on keys in front of the box. The syren or sounding pipe is placed in one of these holes.

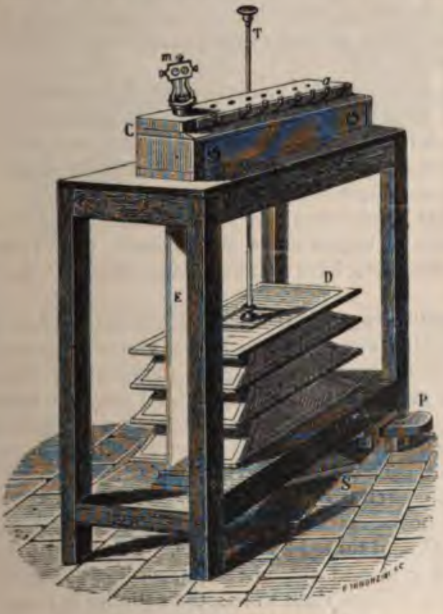


Fig. 172.

229. **Limit of perceptible sounds.**— Before Savart's researc physicists assumed that the ear could not perceive a sound when t number of single vibrations was below 32 for deep sounds, or abo 18,000 for acute sounds. But he showed that these limits were much t close, and that the faculty of perceiving sounds depends rather on th intensity than on their height; so that when extremely acute sounds a not heard, it arises from the fact that they have not been produced wi sufficient intensity to affect the organ of hearing.

By increasing the diameter of the toothed wheel, and consequently th amplitude and intensity of the vibrations, Savart pushed the limit of acu sounds to 48,000 single vibrations in a second.

For deep sounds, he substituted for the toothed wheel an iron ba about two feet long, which revolved on a horizontal axis between tw thin wooden plates, about 0·08 of an inch from the bar. As often as th bar passed, a grave sound was produced, due to the displacement of th air. As the motion became accelerated, the sound became continuo very grave and deafening. By this means Savart found, that with 14 to 16 single vibrations in a second, the ear perceived a distinct but very deep sound.

M. Despretz, however, who has investigated the same subject, disputes Savart's results as to the limits of deep sounds, and holds that no sound is audible that is made by less than 32 single vibrations per second. On the other hand, he maintains that acute sounds are audible up to those corresponding to 73,700 single vibrations per second.

The discordant results obtained by these and other observers for the limit of audibility of higher notes, are no doubt due to the circumstance that different observers have different capacities for the perception of sounds.

230. **Duhamel's graphic method.**—When the syren or Savart's wheel is used to determine the exact number of vibrations corresponding to a given sound, it is necessary to bring the sound which they produce into unison with the given sound, and this cannot be done exactly unless the experimenter have a practised ear. M. Duhamel's graphic method is very simple and exact, and free from this difficulty. It consists in fixing a fine point to the body emitting the sound, and causing it to trace the vibrations on a properly prepared surface.

The apparatus consists of a wood or metal cylinder, A, fig. 173, fixed to a vertical axis, O, and turned by a handle. The lower part of the axis is a screw working in a fixed nut, so that, according as the handle is turned from left to right, or from right to left, the cylinder is raised or depressed. Round the cylinder is rolled a sheet of paper covered with an inadhesive film of lampblack. On this film the vibrations register themselves. This is effected as follows : Suppose the body emitting the note to be a steel rod. It is held firmly at one end, and carries at the other a fine point which grazes the surfaces of the cylinder. If the rod is made to vibrate and the cylinder is at rest, the point would describe a short line; but if the cylinder is turned, the point produces an *undulating trace*, containing as many undulations as the point has made vibrations. Con-quently, the number of vibrations can be counted. It remains only to etermine the time in which the vibrations were made.

There are several ways of doing this. The simplest is to compare the

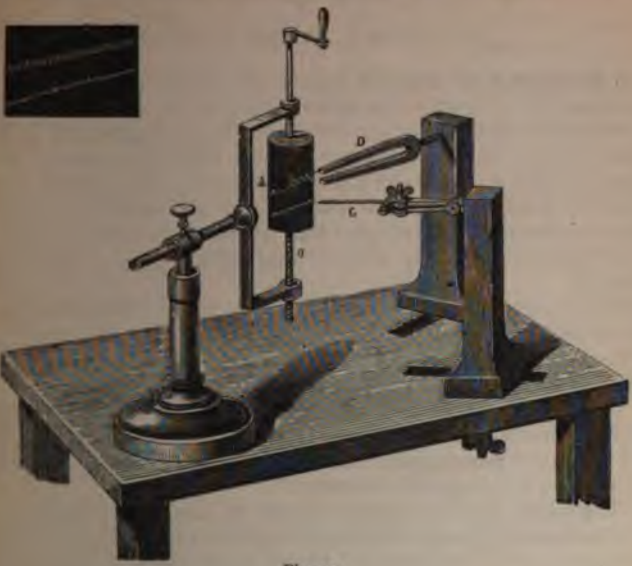


Fig. 173.

urve traced by the vibrating rod with that traced by a tuning-fork 36), which gives a known number of vibrations per second—for example, 00. One prong of the fork is furnished with a point, which is placed contact with the lampblack. The fork and the rod are then set ibrating together, and each produces its own undulating trace. When he paper is unrolled, it is easy by counting the number of vibrations ach has made in the same distance to determine the number of ibrations made per second by the elastic rod. Suppose, for instance, hat the tuning-fork made 150 vibrations, while the rod made 165 ibrations. Now we already know that the tuning-fork makes one ibration in the $\frac{1}{500}$ part of a second, and therefore 150 vibrations in $\frac{150}{500}$ f a second. But in the same time the rod makes 165 vibrations; herefore it makes one vibration in the $\frac{150}{500 \times 165}$ of a second, and hence makes per second $\frac{500 \times 165}{150}$ or 550 vibrations.

CHAPTER III.

THE PHYSICAL THEORY OF MUSIC.

231. **Properties of musical tones.**—A simple musical tone results from a continuous rapid isochronous vibration, provided the number of the vibrations falls within the very wide limits mentioned in the last chapter (229). Musical tones are in most cases compound. The distinction between a simple and a compound musical tone will be explained later in the chapter. The tone yielded by a tuning-fork furnished with a proper resonance box is *simple*; that yielded by a wide-stopped organ pipe, or by a flute, is nearly simple; that yielded by a musical string is compound.

Musical tones have three leading qualities, namely, *pitch*, *intensity*, and *timbre* or *colour*.

i. The *pitch* of a musical tone is determined by the number of vibrations per second yielded by the body producing the tone.

ii. The *intensity* of the tone depends on the *extent* of the vibrations. It is greater when the extent is greater, and less when it is less. It is, in fact, nearly or exactly proportional to the square of the extent or amplitude of the vibrations which produce the tone.

iii. The *timbre* is that peculiar quality of tone which distinguishes a note when sounded on one instrument from the same note when sounded on another. Thus when the C of the treble stave is sounded on a violin, and on a flute, the two notes will have the same pitch, that is, are produced by the same number of vibrations per second, and they may have the same intensity, and yet the two tones will have very distinct qualities, that is, their timbre is different. The cause of the peculiar timbre of tones will be considered later in the chapter.

232. **Musical intervals.**—Let us suppose that a musical tone, which for the sake of future reference we will denote by the letter C, is produced by m vibrations per second; and let us further suppose that any other musical tone, X, is produced by n vibrations per second, n being greater then m; then the interval from the note C to the note X is the ratio n ; m, the interval between two notes being obtained by *division*, not by *subtraction*. Although two or more tones may be separately musical, it by no means follows that when sounded together they produce a pleasurable sensation. On the contrary, unless they are *concordant*, the result is harsh, and usually unpleasing. We have therefore to enquire what *notes* are fit to be sounded together. Now when musical tones are compared, it is found that if they are separated by an interval of 2 : 1, 4 : 1, etc., they so closely resemble one another that they may for most purposes of music be considered as the same tone. Thus, suppose c to stand for a musical note produced by $2m$ vibrations per second, then C and c so closely resemble one another as to be called in music by the same name. The interval from C to c is called an *octave*, and c is

to be an *octave* above C, and conversely C an octave below *c*. If we consider musical sounds that do not differ by an octave, it is found if we take three notes, X, Y, and Z, resulting respectively from p, q, ʳ vibrations per second, these three notes when sounded together will ncordant if the ratio of $p : q : r$ equals 4 : 5 : 6. Three such notes a *harmonic triad*, and if sounded with a fourth note, which is the e of X, constitute what is called in music a *major chord*. Any of otes of a chord may be altered by one or more octaves without ging its distinctive character; for instance, C, E, G, and *c* are a chord, -, *c*, *e*, *g*, form the same chord.

however, the ratio $p : q : r$ equals 10 : 12 : 15, the three sounds are ly dissonant, but not so much so as to disqualify them from pro-g a pleasing sensation, at least under certain circumstances. When three notes and the octave to the lower are sounded together they itute what in music is called a *minor chord*.

;. **The musical scale.**—The series of sounds which connects a note, C, with its octave, *c*, is called the diatonic scale or gamut. notes composing it are denoted by the letters C, D, E, F, G, A, B. scale is then continued by taking the octaves of these notes, namely, ;, *f*, *g*, *a*, *b*, and again the octaves of these last, and so on.

e notes are also denoted by names, viz. *do*, or *ut*, *re*, *mi*, *fa*, *sol*, *la*, *si*, The relations existing between the notes are these:—C, E, G, form jor triad, G, B, *d*, form a major triad, and F, A, *c*, form a major C, G, and F have, for this reason, special names, being called ctively the *tonic*, *dominant*, and *sub-dominant*, and the three triads onic, *dominant*, and *sub-dominant* triads or chords respectively. equently, the numerical relations between the notes of the scale will ven by the three proportions—

$$\mathrm{C : E : G :: 4 : 5 : 6}$$
$$\mathrm{G : B : 2D :: 4 : 5 : 6}$$
$$\mathrm{F : A : 2C :: 4 : 5 : 6}$$

nce if m denotes the number of double vibrations corresponding to note C, the number of vibrations corresponding to the remaining will be given by the following table—

C	D	E	F	G	A	B	*c*
m	$\frac{9}{8}m$	$\frac{5}{4}m$	$\frac{4}{3}m$	$\frac{3}{2}m$	$\frac{5}{3}m$	$\frac{15}{8}m$	$2m$

intervals between the successive notes being respectively—

C to D	D to E	E to F	F to G	G to A	A to B	B to *c*
$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

will be observed here that there are three kinds of intervals, $\frac{9}{8}$, $\frac{10}{9}$, $\frac{6}{5}$; of these the two former are called a *tone*, the last a *semitone*. wo tones however are not identical, but differ by an interval of $\frac{81}{80}$, is called a *comma*. Two notes which differ by a *comma* can be y distinguished by an educated ear. The interval between the and any note is denominated by the position of the latter note in the ; thus the interval from C to G is a fifth. The scale we have now considered is called the *major* scale, as being formed of *major* triad If the minor triad were substituted for the major, a scale would b formed that could be strictly called a *minor* scale. As scales are usuall written, however, the *ascending* scale is so formed that the tonic bears minor triad, the dominant and self-dominant bear *major* triads, while i the *descending* scale they all bear *minor* triads. Practically, in musica composition, the dominant triad is always *major.* If the ratios given above are examined, it will be found that in the major scale the interva from C to E equals $\frac{5}{4}$, while in the minor scale it equals $\frac{6}{5}$. The former interval is called a major third, the latter a *minor* third. Hence the major third exceeds the minor third by an interval of $\frac{25}{24}$. This interval is called a semitone, though very different from the interval above called by that name.

A complete discussion of the number of notes, and the intervals between them, will be found in an article by Mr. Ellis, in vol. xiii. of the *Proceedings of the Royal Society* (p. 93), 'On a Perfect Musical Scale.'

234. **On semitones and on scales with different key notes.**—It will be seen from the last article that the term 'semitone' does not denote a constant interval, being in one case equivalent to $\frac{16}{15}$ and in another to $\frac{25}{24}$. It is found convenient for the purposes of music to introduce notes intermediate to the seven notes of the gamut ; this is done by increasing or diminishing those notes by an interval of $\frac{25}{24}$. When a note (say C) is increased by this interval, it is said to be sharpened, and is denoted by the symbol C♯, called 'C sharp ;' that is, C♯ ÷ C = $\frac{25}{24}$. When it is decreased by the same interval, it is said to be flattened, and is represented thus—B♭, called 'B flat ;' that is, B ÷ B♭ = $\frac{25}{24}$. If the effect of this be examined, it will be found that the number of notes in the scale from C up to has been increased from seven to twenty-one notes, all of which can be easily distinguished by the ear. Thus, reckoning C to equal 1, we have—

C	C♯	D♭	D	D♯	E♭	E	etc.
1	$\frac{25}{24}$	$\frac{27}{25}$	$\frac{9}{8}$	$\frac{75}{64}$	$\frac{6}{5}$	$\frac{5}{4}$	etc.

Hitherto we have made the note C the tonic or *key note.* Any other of the twenty-one distinct notes above mentioned, e.g. G, or F, or C♯ etc., may be made the key note, and a scale of notes constructed with reference to it. This will be found to give rise in each case to a series of notes, some of which are identical with those contained in the series of which C is the key note, but most of them different. And of course the same would be true for the minor scale as well as for the major scale, and indeed for other scales which may be constructed by means of the fundamental triads.

235. **On musical temperament.**—The number of notes that arise from the construction of the scales described in the last article is enor mous ; so much so as to prove quite unmanageable in the practice of music and particularly for music designed for instruments with fixed notes such as the pianoforte. Accordingly, it becomes practically important reduce the number of notes, which is done by slightly altering their jus proportions. This process is called *temperament.* By tempering th

cases, however, more or less dissonance is introduced, and accordingly several different systems of temperament have been devised for rendering this dissonance as slight as possible. The system usually adopted —at least in intention—is called the system of *equal temperament.* It consists in the substitution between C and *c* of eleven notes at equal intervals, each interval being, of course, the twelfth root of 2, or 1·05946. By this means the distinction between the semitones is abolished, so that, for example, C♯ and D♭ become the same note. The scale of twelve notes thus formed is called the *chromatic scale.* It of course follows that major triads become slightly dissonant. Thus, in the diatonic scale, if we reckon C to be 1, E is denoted by 1·25000, and G by 1·50000. On the system of equal temperament, if C is denoted by 1, E is denoted by 1·25992 and G by 1·49831.

236. **The number of vibrations producing each note. The tuning-fork.**—Hitherto we have denoted the number of vibrations corresponding to the note C by *m*, and have not assigned any numerical value to that symbol. In the theory of music it is usual to assign 256 double vibrations to the middle C. This, however, is arbitrary. An instrument is in tune provided the intervals between the notes are correct, when C is yielded by any number of vibrations per second not differing much from 256. Moreover, two instruments are in tune with one another if, being separately in tune, they have any one note, for instance, C, yielded by the same number of vibrations. Consequently, if two instruments have one note (say C) in common, they can then be brought into tune jointly by having their remaining notes separately adjusted with reference to that fundamental note. A tuning-fork is an instrument yielding a constant sound, and is used as a standard for tuning musical instruments. It consists of an elastic steel rod, bent as represented in fig. 174. It is made to vibrate either by drawing a bow across the ends, or by striking one of the legs against a hard body, or by rapidly separating the two legs by means of a steel rod, as shown in the figure. The vibration produces a note which is always the same for the same tuning-fork. The note is strengthened by fixing the tuning-fork on a box open at one end, called a *resonance box.*

It has been remarked for some years that not only has the pitch of the tuning-fork, that is, *concert pitch,* been getting higher in the large theatres of Europe, but also that it is not the same in London, Paris, Vienna, Milan, etc. This is a source of great inconvenience both to composers and singers, and a commission was appointed to establish in France a tuning-fork of uniform pitch, and to prepare a standard which would serve as an invari-

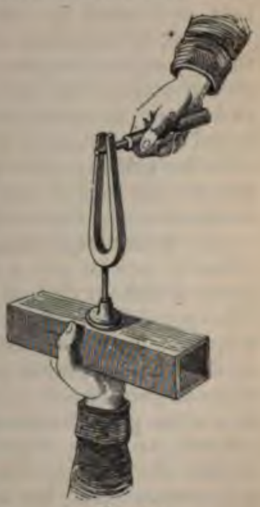


Fig. 174.

able type. In accordance with the recommendations of that body, *normal tuning-fork* has been established, which is compulsory on musical establishments in France, and a standard has been deposited the Conservatory of Music in Paris.

It performs 870 single vibrations per second, and gives the standa note *a*, or the *a* in the treble stave. Consequently, with reference to th standard, the middle C would result from 261 double vibrations p second.

237. **Wave length of a given note.**—Knowing the number of vib tions which a sounding body makes in a second, the corresponding wa length is easily calculated. For since sound travels at about 1120 f in a second, if a body only made one vibration in a second its wa length would be 1120 feet: if it made two, the wave length would half of 1120 feet; if it made three, the third, and so on—that is, that *wave length of any note is the quotient obtained by dividing the velo of sound by the number of vibrations*; and this whatever the height of sound, since the velocity is the same for high and low notes.

Hence, calling v the velocity of sound, l the wave length, n the num of vibrations in a second, we have $v = ln$, from which $n = \frac{v}{l}$, that is, th the number of vibrations is inversely as the wave length.

238. **On compound musical tones and harmonics.** — When a given note (say C) is sounded on most musical instruments, not th tone alone is produced, but a series of tones, each being of less inten than the one preceding it. If C, which may be called the *prima* tone, is denoted by unity, the whole series is given by the numb 1, 2, 3, 4, 5, 6, 7, etc.; in other words, first the primary C is sounde then its octave becomes audible, then the fifth to that octave, then th second octave, then the third, fifth, and a note between the sixth a seventh to the second octave, and so on. These secondary tones a called the *harmonics* of the primary *tone*. Though feeble in compari with the primary tone, they may, with a little practice, be heard, wh the primary tone is produced on most musical instruments; when, instance, one of the lower notes is sounded on the pianoforte.

239. **Helmholtz's analysis of sound.**—For the purpose of expe mentally proving the presence of the harmonics as distinct tones, P fessor Helmholtz devised an instrument which he called a *resonance gl* The principle involved in its construction is this: A volume of contained in an open vessel, for example a bottle, when caused to vibr tends to yield a certain note, and consequently when that note is sound in its neighbourhood, to strengthen it (214). A resonance globe, fig. 17 is a glass globe furnished with two openings, one of which, *a*, is tur towards the origin of the sound, and the other, *b*, by means of an in rubber tube, is applied to the ear. If the tone proper to the resona globe exists among the harmonics of the compound tone that is sound it is strengthened by the globe, and thereby rendered distinctly audi Further, other things being the same, the note proper to a given gl depends on the diameter of the globe and that of the uncovered open

sequently, by means of a series of such globes, the whole series of monics in a given compound tone can be rendered distinctly audible, their existence put beyond a doubt.

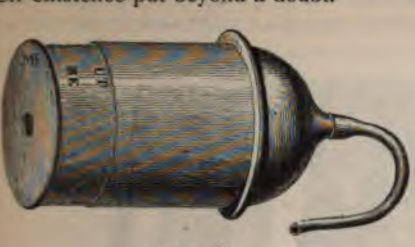


Fig. 176.

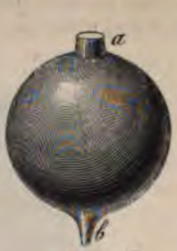


Fig. 175.

König, the eminent acoustical instrument maker, has made an import modification in the resonance globe to which he has given the form resented in fig. 176. The resonator is cylindrical, and the end which eives the sound can be drawn out, so that the volume may be increased pleasure. As the sound thereby becomes deeper, the same resonator y be tuned to a variety of notes. On the tubulure fits a caoutchouc e by which the vibrations may be transmitted in any direction.

240. **König's apparatus for the analysis of sound.**—As the successive application to the ear of various resonators is both slow and ious, König has devised a remarkable apparatus in which a series resonators act on manometric flames (262), the sounds thus become ible, and may be shown to a large auditory.

It consists of an iron frame (fig. 177) on which are fixed in two parallel es fourteen resonators tuned so as to give the notes from F_1 to C_5, that to say, four octaves and a half; or notes of which the highest give the ver harmonics of the primary. On the right is a chamber, C, which is pplied with coal gas by the caoutchouc tube, D, and on which are ced eight gas jets, each provided with a manometric capsule (251, 263). ch jet is connected with the chamber C by a special caoutchouc tube, ile behind the apparatus a second tube connects the same jet to one of e resonators. On the right of the jets is a system of rotating mirrors ntical with that described.

These details being understood, suppose the largest resonator on the ght tuned to resound with the note 1, and seven others with the harmonics this note. Let the sound 1 be produced in part of this apparatus; if it simple, the lower resonator alone answers, and the corresponding flame alone dentated; but if the fundamental note is accompanied by one or ore of its harmonics, the corresponding resonators speak at the same ne, which is recognised by the dentation of their flames; and thus the nstituents of each sound may be detected.

241. **Synthesis of sounds.**—Not only has Helmholtz succeeded in composing sounds into their constituents; he has verified the result of analysis by performing the reverse operation, the synthesis; that is, has reproduced a given sound by combining the individual sounds of

which his resonators had shown that it was composed. The apparatus which he used for this purpose consists of eleven tuning-forks, the first of which yields the fundamental note of 256 vibrations, or C_2, nine others its harmonics, while the eleventh serves as make and break to cause the

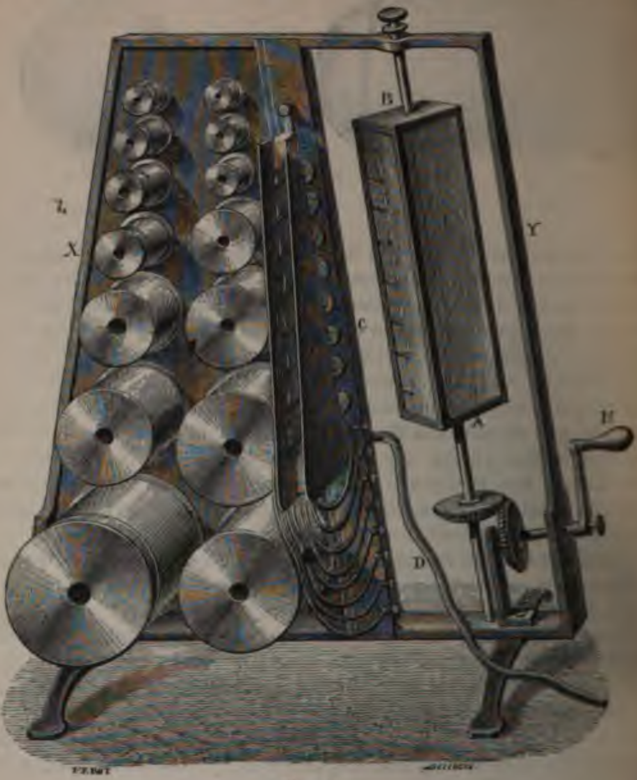


Fig. 177.

diapasons to vibrate by means of electro-magnets. Each diapason has a special electro-magnet, and moreover a resonator, which strengthens it.

All these diapasons and their accessories are arranged in parallel lines of five (fig. 178), the first comprising the fundamental note and its uneven harmonics, 3, 5, 7 and 9; the second the even harmonics, 2, 4, 6, 8 and 10; beyond, there is the diapason break K arranged horizontally. One of its limbs is provided with a platinum point which grazes the surface of mercury contained in a small cup, the bottom of which is connected, by a copper wire, with an electro-magnet placed in front of the diapason.

The apparatus being thus arranged, a wire from a voltaic battery i connected with the binding screw, *c*, and this with the electro-magnet, E which in turn is connected with those of the nine following diapasons d then with the diapason K itself. So long as the diapason does not rate, the current does not pass, for the platinum point does not dip in the rcury cup which is connected with the other pole of the battery. But en the diapason is made to vibrate by means of a bow, the current sses. Owing to their elasticity, the limbs of the tuning-fork soon ert to their original position, the point is no longer in the mercury, the rrent is broken, and so on at each double vibration of the diapason. is intermittence of the current being transmitted to all the other ctro-magnets, they are alternately active and inactive. Hence they mmunicate to all the diapasons by their attraction the same number of rations. This is the case with the diapason 1, which is tuned in unison

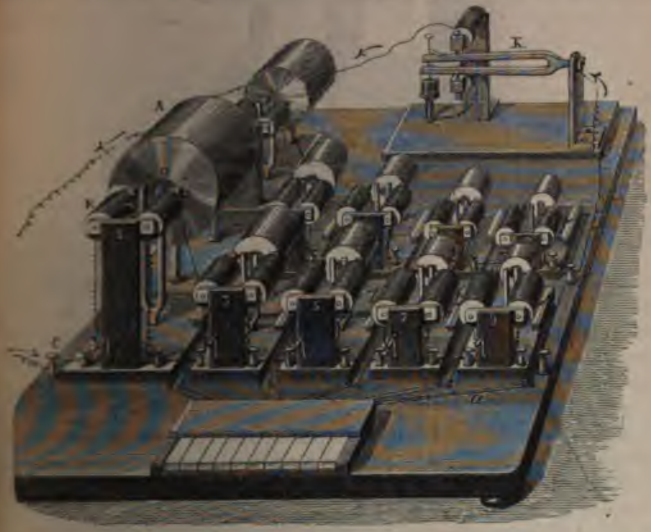


Fig. 178.

th the diapason break; but the diapason 3 being tuned to make three es as many vibrations, makes three vibrations at each break of the rrent; that is to say, the electro-magnet only attracts it at every third bration; in like manner, diapason *b* only receives a fresh impulse every e vibrations, and so on.

The following is the working of the apparatus. The resonator of each apason is closed by a clapper O (fig. 179), so that the sounds made by e diapasons are scarcely perceptible when the clappers are lowered. ch of these is fixed to the end of a bent lever, the shorter arm of which worked by a cord *a*, which is connected with one of the keys of a key-ard placed in front of the apparatus (fig. 178). When a key is pressed, the cord moves the lever, which raises the clapper, and the nator then acts by strengthening its diapason. Hence by depressing y keys, we may add to the fundamental sounds *any of* the nine primary harmonics, and thus reproduce the sounds, the composition of which h been determined by analysis. Thus by depressing all the keys at on we obtain the sound of an open pipe in unison with the deepest diapas By depressing the key of the fundamental notes and those of its unev harmonics, we obtain the sound of a closed pipe.

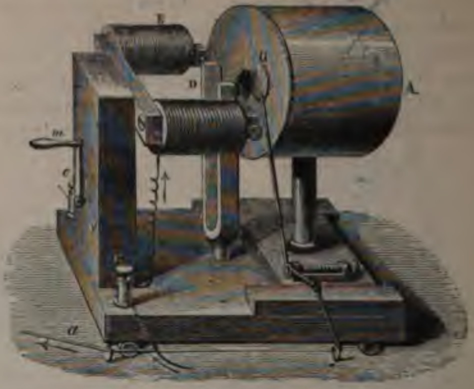


Fig. 179.

242. **Results of Helmholtz's researches.**—By both his analytical an synthetical investigations into sounds of the most kinds, those fro various musical instruments, the human voice, and even noises, Helm holtz has fully succeeded in explaining the different *timbre* or quality o these sounds. It is due to the different intensities of the harmonic which accompany the primary tones of those sounds. The leadin results of these researches into the colour of sounds may be thus stated

i. Simple tones, as those produced by a tuning-fork with a resonan box, and by wide covered pipes, are soft and agreeable without any rough ness, but weak, and in the deeper notes dull.

ii. Musical sounds accompanied by a series of harmonics, say up to th sixth, in moderate strength are full and musical. In comparison wi simple tones they are grander, richer, and more sonorous. Such are th sounds of open organ pipes, of the pianoforte, etc.

iii. If only the uneven harmonics are present, as in the case of narro covered pipes, of pianoforte strings struck in the middle, clarionets, et the sound becomes indistinct: and when a greater number of harmoni are audible, the sound acquires a nasal character.

iv. If the harmonics beyond the sixth and seventh are very distinc the sound becomes sharp and rough. If less strong, the harmonics ar not prejudicial to the musical usefulness of the notes. On the contrar they are useful as imparting character and expression to the music. O this kind are most stringed instruments, and most pipes furnished wi tongues, etc. Sounds in which harmonics are particularly strong acqu thereby a peculiarly penetrating character; such are those yielded b brass instruments.

V. To form a given vowel sound one or more characteristic notes which are always the same must be added. These change with the syllable pronounced, but depend neither on the height of the note, nor on the person who emits them.

A popular but adequate account of Helmholtz's principal results will be found in Helmholtz's 'Popular Scientific Lectures,' Longmans, 1873.

243. **Production and perception of sounds.**—Vocal sounds originate in the larynx in consequence of air being forced through a slit formed of two membranes called the *vocal chords*. These can be tightened or relaxed by means of certain muscles, and thus high or low notes can be produced. The notes produced by men are deeper than those of women or boys, because in them the larynx is longer and the vocal chords larger and thicker; hence, though equally elastic, they vibrate less swiftly. Chest notes are due to the fact that the whole membrane vibrates, while the falsetto is produced by a vibration of the extreme edges only. The ordinary compass of the voice is within two octaves, though this is exceeded by some celebrated singers. Catalani, for instance, is said to have had a range of 3½ octaves.

The sound of the human voice is very complex and rich in harmonics, for the mouth and the various cavities opening into the mouth act as resonators; as the note changes with their extent, with the degree to which the mouth is opened and the shape given to it, certain harmonics are strengthened or not, and thus the voice acquires different timbre.

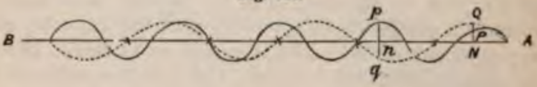
Without giving an account of the anatomy of the ear we may state succinctly how Helmholtz explains the perception by the ear of the most complicated sounds.

The recent observations of M. Corti have shown that the inner membrane of the cochlea is lined with about 3,000 extremely minute fibres which are the termination of the acoustic nerve. Each of these, which are called *Corti's fibres*, seems to be tuned for a particular note as if it were a small resonator. It thus only vibrates in unison with this note, and is deaf for all others. Hence each simple note only causes one fibre to vibrate, while compound notes cause several; just as when we sing with a piano, only the fundamental note and its harmonics vibrate. Hence, however complex external sounds may be, these microscopic fibres can analyse it and reveal the constituents of which it is formed.

244. **Beats.**—When two simple tones are sounded together, it is in many cases found that they alternately strengthen and weaken one another. When this is so, they are said to *beat* with one another. This may be explained as follows: Suppose AB, in fig. 180, to be a row of particles transmitting the sound; suppose the vibrations producing the one tone to be indicated by the continuous curved line; then, on the one hand, the ordinates of the different points of AB give the velocities with which those points are *simultaneously* moving, and, on the other hand, each point will have *successively* the different velocities represented by the successive ordinates. In like manner let the dotted line show the vibrations which produce the second tone. And, for the sake of distinctness, suppose the

number of vibrations per second producing the former tone to be to that producing the latter in the ratio of 3 : 2. Now let us consider any point which when at rest occupies the position N; draw the ordinate cutting the former curve in P and the latter in Q. If the tones were sounded separately, the velocity of N at a given instant produced by the former tone would be PN, and that of N at the same instant produced by the latter tone would be QN. Consequently, as they are sounded together, the actual velocity of N at the given instant is the sum of these, or $PN+QN$. If at the same instant we consider the point *n*, its velocity will consist of *pn* and *nq* jointly, but as these are in opposite directions, its actual amount will be $pn-nq$. Hence the actual velocity resulting from the coexistence of the two tones will be indicated by the curve in fig. 181,

Fig. 180.



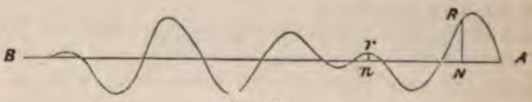


Fig. 181.

whose ordinates equal the (algebraical) sum of the corresponding ordinates of the two curves in fig. 180; that is, if AN, A*n*, . . . represent equal distances in both figures, the curve is described by taking RN equal to $PN+QN$, *rn* equal to $pn-qn$, and so on. This curve shows by its successive ordinates the simultaneous velocities of the different particles of AB, and the successive velocities communicated to the drum of the ear. An inspection of the figure will show that the velocities are first great, then small, then great, and so on, the drum being first moved rapidly for a short time, then for a short time nearly brought to rest, and so on. In short, the effect of the beating of tones on the ear as compared with that of a continuous tone is strictly analogous to the effect produced on the eye by a flickering as compared with a steady light.

It may be proved that when two simple tones are produced by *m* and *n* double vibrations per second, they produce $m-n$ beats per second; thus, if C is produced by 128, and D by 144 double vibrations per second, they will on being sounded together produce 16 beats per second. It has been ascertained that the beats produced by two tones are not audible unless the ratio $m:n$ is less than the ratio 6 : 5. Hence, in the case represented by fig. 181, though the alternations of intensity exist, they would not be audible. Also, if the tones have very different intensities, the intensity of the beat is very much disguised.

It is found that when beats are fewer than 10 per second or more than 70 per second they are disagreeable, but not to the extent of producing discord. Beats from 10 to 70 per second may be regarded as the source of all discord in music, the maximum of dissonance being attained when about 30 beats are produced per second. For example, if *c* and B are sounded together, the effect is very discordant, the interval between those notes being 16 : 15, so that the beats are audible, and the number of beats per second being 16. On the other hand, if C, E, and G are sounded together there is no dissonance, but if C, E, G, B are sounded together the discord is very marked, since C produces *c*, which is discordant with B. It will be remarked that C, E, G is a major triad, while E, G, B is a minor triad.

A compound musical tone, being composed of simple tones represented by 1, 2, 3, 4, 5, 6, 7, etc., does not give rise to any simple tones capable of producing an audible beat up to the seventh—the sixth and seventh are the first that produce an audible beat. It is for this reason that there is no trace of roughness in a compound tone, unless the seventh harmonic be audible.

If we were to represent graphically a compound tone, we should proceed to construct a curve out of simple tones of different intensities in the same manner as fig. 181 is constructed from two simple tones of equal intensity represented by fig. 180. It is evident that the resulting curve will take different *forms* according to the presence or absence of different harmonics and their different intensities; in other words, the *colour* of the notes produced by different instruments will depend upon the *form* of the vibrations producing the sound.

245. **Combinational tones.** — Besides the beats produced when two musical notes are sounded together, there is another and distinct phenomenon, which may be thus described: Suppose two simple tones to be simultaneously produced by vibrations of finite extent, and of n and m vibrations per second. It has been shown by Helmholtz that they generate a series of other tones. The principal one of these, which may be called the *differential tone*, is produced by $n-m$ vibrations per second. Its intensity is generally very small, but it is distinctly audible in beats. It has been called the *grave harmonic*, as generally its pitch is much lower than that of the notes by which it is generated. It has been supposed to be caused by the beats becoming too numerous to be distinguished, and coalescing into a continuous sound, and this supposition was countenanced by the fact that its pitch is the same as the beat number. The supposition is shown to be erroneous, first, by the existence of the differential tones for intervals that do not beat, and secondly, by the fact that, under certain circumstances, both the beats and the differential tones may be heard together.

246. **The physical constitution of musical chords.**—Let us suppose two compound tones to be sounded together, say C and G, then we obtain two series of tones each consisting of a primary and its harmonics, namely, denoting C by 4, the two series, 4, 8, 12, 16, . . . and 6, 12, 18, 24 etc. Now, if instead of producing the two notes C and G, we had sounded the octave below C, we should have produced the series, 2, 4, 6, 8, 10, 12, 14, 16, 18, etc. It is plain that the two former series when joined differ from the last in the following respects: (*a*) The primary tone 2 is omitted. (*b*) In the case of the last series, the consecutive tones continually decrease in intensity, whereas in the two former

series, 4 and 6 are of the same intensity, 8 is of lower intensity, but the two 12's will strengthen each other, and so on. (*c*) Certain of the harmonics of the primary 2 are omitted; for example, 10, 14, etc., do not occur in either of the two former series. In spite of these differences, however, the two compound notes affect the ear in a manner very closely resembling a single compound tone; in short, they coalesce into a single tone with an artificial colour. It may be added that in the case above taken C and G produce as a combination tone 2 (that is, 6 − 4), so that, strictly speaking, the 2 is not wanted in the series produced by C and G, only it exists in very diminished intensity. The same explanation will apply to all possible chords; for example, in the case of the major chord, C, E, G, we have a tone of artificial colour expressed by the series of simple tones, 4, 5, 6, 8, 10, 12, 15, 16, 18, etc., together with the combination tones, 1, 1, 2. It will be remarked that in the whole of this series there are no dissonant tones introduced, except 15, 16, and 16, 18, and this dissonance will be inappreciably slight, since 15 is the third harmonic of 5, and the 16 the fourth harmonic of 4, so that their intensities will be different, as also will be the intensities of 16 and 18. On the other hand, nearly all the tones which form a *natural* compound tone are present, namely, there are 1, 2, 4, 5, 6, 8, 10, 12, etc., in place of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, etc. In short, the major triad differs only from a *natural* compound tone in that it consists of a series of simple tones of different intensities, and omits those which by beating with its neighbouring tone would produce dissonance, for example, 7, which would beat with 6 and 8; 9, which would beat with 8 and 10; and 11, which would beat with 10 and 12. It is this circumstance which renders the major chord of such great importance in harmony. If the constituents of the minor chord are similarly discussed, namely, three compound tones whose primaries are proportional to 10, 12, 15, it will be found to differ from the major chord in the following principal respects: (*a*) The primary of the natural tone to which it approximates is very much deeper than that of the corresponding major chord. (*b*) It introduces the *differential* tones, 2, 3, 5, which form a major chord. Now it has already been remarked that when a major and minor chord are sounded together, they are distinctly dissonant; for example, when C, E, G, A, are sounded together. Accordingly, the fact of the differential tones forming a major chord shows that an elementary dissonance exists in every minor chord.

CHAPTER IV.

VIBRATIONS OF STRETCHED STRINGS, AND OF COLUMNS OF AIR.

247. **Vibrations of strings.**—By a *string* is meant the string of a musical instrument, such as a violin, which is stretched by a certain force and is commonly of catgut or is a metallic wire. The vibrations which strings experience may be either *transversal* or *longitudinal*, but practically the former are alone important. *Transversal vibrations* may b

produced by drawing a bow across the string, as in the case of the violin; or by striking the string, as in the case of the pianoforte; or by pulling them transversely, and then letting them go suddenly, as in the case of the guitar and the harp.

248. **Sonometer.**—The *sonometer* is an apparatus by which the transverse vibrations of strings may be studied. It is also called *monochord*, because it has generally only one string. In addition to the string, it consists of a thin wooden box to strengthen the sound; on this there are two fixed bridges, A and D (fig. 182), over which passes the string, which is usually a metallic wire. This is fastened at one end, and stretched at the other by a weight, P, which can be increased at will. By means of a third movable bridge, B, the length of that portion of the wire which is to be put in vibration can be altered at pleasure.

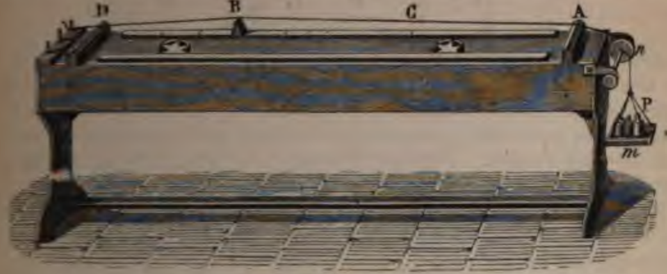


Fig. 182.

249. **Laws of the transverse vibrations of strings.**—If l be the length of a string, that is, the vibrating part between two bridges, A and B (fig. 182), r the radius of the string, d its density, P the stretching weight, and n the number of vibrations per second, it is found by calculation that $n = \frac{1}{2rl}\sqrt{\frac{P}{\pi d}}$; π being the ratio of the circumference to the diameter. If c denote the length of the string or wire whose weight is the same as the stretching weight, it is plain that $P = \pi r^2 cdg$, where g is the accelerating force of gravity. On substituting this value for P, we find that $n = \frac{\sqrt{cg}}{2l}$. If c and l are measured in inches, and the value of the accelerating force of gravity at London (384·29 in seconds and inches) be used, this formula takes the shape in which it is usually written :—

$$n = \frac{9{\cdot}8 \times \sqrt{c}}{l}$$

From the above formula the following laws have been deduced :—

I. *The stretching weight or tension being constant, the number of vibrations per second is inversely as the length.*

II. *The number of vibrations per second is inversely as the radius of the string.*

III. *The number of vibrations per second is directly as the square root of the stretching weight or tension.*

IV. *The number of vibrations per second of a string is inversely as the square root of its density.*

These laws are applied in the construction of stringed instruments, in which the length, diameter, tension, and substance of the strings are so chosen, that given notes may be produced from them.

251. **Experimental verification of the laws of the transverse vibration of strings.**—*Law of the lengths.* In order to prove this law, we may call to mind that the relative numbers of vibrations of the notes of the gamut are

C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

If now the entire length of the sonometer be made to vibrate, and then, by means of the bridge B, the lengths $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$. $\frac{8}{15}$, $\frac{1}{2}$, which are the inverse of the above numbers, be successively made to vibrate, all the notes of the gamut are successively obtained, which proves the first law.

Law of the radius. This law is verified by stretching upon the sonometer two cords of the same material, the diameters of which are as 3 to 2, for instance. When these are made to vibrate, the second cord gives the *fifth* above the other; which shows that it makes three vibrations while the first makes two.

Law of the tensions. Having placed on the sonometer two identical strings, they are stretched by weights which are as 4 : 9. The second now gives the fifth of the first, from which it is concluded that the numbers of their vibrations are as 2 : 3, that is, as the square roots of the tensions. If the two weights are as 16 to 25, the major third or $\frac{5}{4}$ would be obtained.

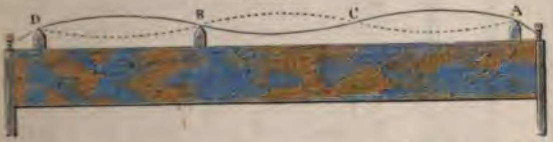
Law of the densities. Two strings of the same radius but different densities are fixed on the sonometer. Having been subjected to the same stretching weight, the position of the movable bridge on the denser one is altered until it is in unison with the other string. If then d and d' are the densities of the two strings, and l and l' the lengths which vibrate in unison, we find $\frac{l}{l'}=\frac{\sqrt{d}}{\sqrt{d'}}$. But as we know from the first law that $\frac{l}{l'}=\frac{n'}{n}$, we have $\frac{n'}{n}=\frac{\sqrt{d}}{\sqrt{d'}}$, which verifies this law.

251. **Nodes and loops.**—Let us suppose the string AD (fig. 182) to begin vibrating, the ends A and D being fixed, and while it is doing so, let a point, B, be brought to rest by a stop, and let us suppose DB to be one-third part of AD. The part DB must now vibrate about B and D as fixed points in the manner indicated by the continuous and dotted lines; now all parts of the same string tend to make a vibration in the same time; accordingly, the part between A and B will not perform a single vibration, but will divide into two at the point C, and vibrate in the manner shown in the figure. If BD were one-fourth part of AD (fig. 183), the part AB would be subdivided at C and C′ into three vibrating portions each equal to BD. The points B, C, C′ are called *nodes* or *nodal points*; the middle point of the part of the string between any two conse-

ve nodes is called a *loop* or a *ventral segment.* It will be remarked the ratio of BD : BA must be that of some two whole numbers, for nple, 1 : 2, 1 : 3, 2 : 3, etc., otherwise the nodes cannot be formed, e the two portions of the string cannot then be made to vibrate in the ie time, and the vibrations will interfere with and soon destroy one ther.

f now we refer to fig. 183, the existence of the node at C can be easily ved by bending some light pieces of paper, and placing them on the

Fig. 183.



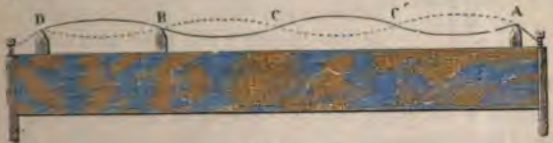


Fig. 184.

ng. Say three pieces, one at C and the others respectively midway veen B and C, and between C and A. The one at C experiences only ry slight motion, and remains in its place, thereby proving the exist- t of a node at C ; the other two are violently shaken, and in most s thrown off the string.

Vhen a musical string vibrates between fixed points A and B, its ion is not quite so simple as might be inferred from the above ription. In point of fact, partial vibrations are soon produced, and rimposed upon the primary vibrations. The partial vibrations cor- ond to the half, third, fourth, etc. parts of the string. It is by these ial vibrations that the harmonics are produced which accompany the ary note due to the primary vibrations.

2. **Wind instruments.**—In the cases hitherto considered the sound lts from the vibrations of solid bodies, and the air only serves as a cle for transmitting them. In wind instruments, on the contrary, n the sides of the tube are of adequate thickness, the enclosed column r is the sonorous body. In fact, the substance of the tubes is without ence on the primary tone; with equal dimensions it is the same her the tubes are of glass, of wood, or of metal. These different ma- ls simply do no more than give rise to different harmonics, and impart ferent quality to the compound tone produced.

reference to the manner in which the air in tubes is made to vibrate, instruments are divided into *mouth* instruments and *reed* instru- s.

. **Mouth instruments.**—In mouth instruments all parts of the hpiece are fixed. Fig. 185 represents the mouthpiece of an organ

pipe, and fig. 185 that of a whistle, or of a flageolet. In both figu
aperture *ib* is called the mouth; it is here that air enters the pipe
o are the *lips*, the upper one of which is b
The mouthpiece is fixed at one end of
the other end of which may be either
or closed. In fig. 186 the tube can be fi
a wind-chest by means of the foot P.

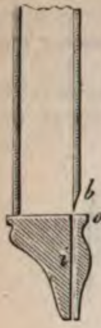


Fig. 185.

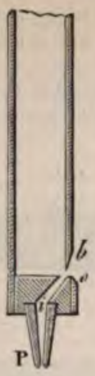


Fig. 186.

When a rapid current of air enters
mouth, it strikes against the upper lip,
shock is produced which causes the air
from *bo* in an intermittent manner. In th
pulsations are produced which, transmi
the air in the pipe, make it vibrate, and
is the result. In order that a pure no
be produced, there must be a certain
between the form of the lips and the ma
of the mouth; the tube also ought to
great length in comparison with its di
The number of vibrations depends in ger
the dimensions of the pipe, and the velocity of the current of air.

254. **Reed instruments.**—In reed instruments a simple elastic
sets the air in vibratio
tongue, which is ei
metal or of wood, is
by a current of air
mouthpieces of the ob
bassoon, the clarion
child's trumpet, are d
applications of the
which, it may be ren
is seen in its simplest
the Jew's harp. Som
pipes are reed pipes,
are mouth pipes.

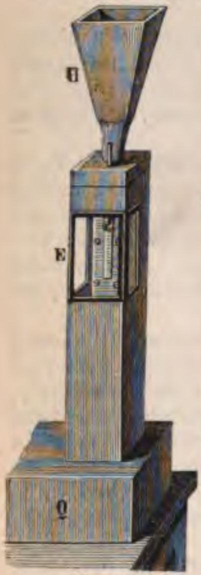


Fig. 187.

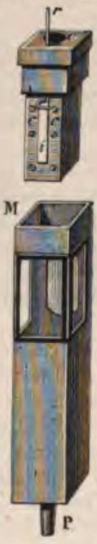


Fig. 188.

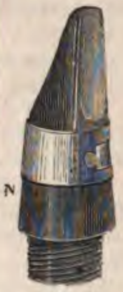


Fig. 189.

Fig. 187 represents
of a reed pipe as con
shown in lectures. It
on the wind-chest
bellows, and the vib
of the reed can b
through a piece of gl
fitting into the si
wooden horn, H, stre
the sound.

Fig. 188 shows th
out of the pipe. It consists of four pieces: 1st, a rectangular
tube closed below and open above at *o*; 2nd, a copper plate *cc*
one side of the tube, and in which there is a longitudinal a

through which air passes from the tube MN to the orifice *o*; 3rd, a thin elastic plate, *i*, called the *tongue*, which is fixed at its upper end, and which grazes the edge of the longitudinal aperture, nearly closing it; 4th, a curved wire, *r*, which presses against the tongue, and can be moved up and down. It thus regulates the length of the tongue, and determines the pitch of the note. It is by this wire that reed pipes are tuned. The reed being replaced in the pipe MN, when a current of air enters by the foot P, the tongue is compressed, it bends inwards, and affords a passage to air, which escapes by the orifice *o*. But, being elastic, the tongue regains its original position, and performing a series of oscillations, successively opens and closes the orifice. In this way sonorous waves result and produce a note, whose pitch increases with the velocity of the current.

In this reed the tongue vibrates alternately before and behind the aperture, merely grazing the edges, as is seen in the harmonium, concertina, etc.; such a reed is called a *free reed*. But there are other reeds called *beating reeds*, in which the tongue, which is larger than the orifice, strikes against the edges at each oscillation. The reed of the clarionet, represented in fig. 189, is an example of this; it is kept in its place by the pressure of the lips. The reeds of the hautboy and bassoon are also of this kind.

255. **Of the tones produced by the same pipe.**—Daniel Bernouilli discovered that the same organ pipe can be made to yield a succession of tones by properly varying the force of the current of air. The results he arrived at may be thus stated :—

i. If the pipe is open at the end opposite to the mouthpiece, then, denoting the primary tone by 1, we can, by gradually increasing the force of the current of air, obtain successively the tones 2, 3, 4, 5, etc., that is to say, the *harmonics* of the primary tone.

ii. If the pipe is closed at the end opposite to the mouthpiece, then, denoting the primary tone by 1, we can, by gradually increasing the force of the current of air, obtain successively the tones 3, 5, 7, etc., that is to say, the uneven *harmonics* of the primary tone.

It must be added that if a closed and an open pipe are to yield the same primary tone, the closed pipe must be half the length of the open pipe, if in other respects they are the same.

In any case it is impossible to produce from the given pipe a tone not included in the above series respectively.

Although the above laws are enunciated with reference to an organ pipe, they are of course true of any other pipe of uniform section.

256. **On the nodes and loops of an organ pipe.**—The vibrations of the air producing a musical tone take place in a direction parallel to the axis of the pipe—not transversely, as in the case of the portions of a vibrating spring. In the former case, however, as well as in the latter, the phenomena of *nodes* and *loops* may be produced. But now by a *node* must be understood a section of the column of air contained in the pipe, where the particles remain at rest, but where there are rapid alternations of *condensation* and *rarefaction*. By a *loop* or *ventral segment* must be

understood a section of the column of air contained in the pipe where the vibrations of the particles of air have the greatest amplitudes, and where there is no change of density. The sections of the column of air are, of course, made at right angles to its axis. When the column of air is divided into several vibrating portions, it is found that the distance between any two consecutive loops is constant, and that it is bisected by a node. We can now consider separately the cases of the open and closed pipes.

i. In the case of a stopped pipe, the bottom is always a node, for the layer of air in contact with it is necessarily at rest, and only undergoes variations in density. At the mouthpiece, on the contrary, where the air has a constant density, that of the atmosphere, and the vibration is at its maximum, there is always a loop. In any stopped pipe there is at least one node and one loop (fig. 190); the pipe then yields its fundamental note, and the distance VN from the loop to the node is equal to half a condensed or rarefied wave length.

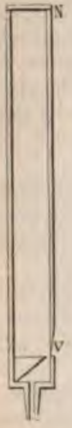


Fig. 190.

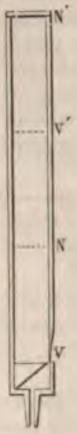


Fig. 191.

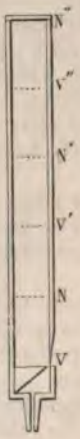


Fig. 192.

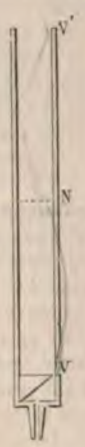


Fig. 193.

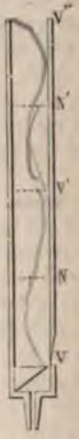


Fig. 194.

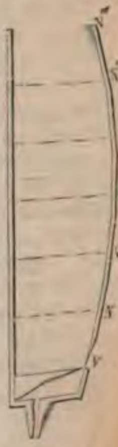


Fig. 195.

If the current of air be forced, the mouthpiece always remains a loop, and the bottom a node, the column divides into three equal parts (fig. 191) and an intermediate node and loop are formed. The sound produced is the first harmonic. When the second harmonic (5) is produced, there are two intermediate nodes and two loops, and the tube is then subdivided into five equal parts (fig. 192), and so on.

ii. In the case of the open pipe, whatever tone it produces, there must be a loop at each end, since the inclosed column of air is in contact with the external air at those points. When the primary tone is produced, there will be a loop at each end, and a node at the middle section of the pipe, the nodes and loops dividing the column into *two* equal parts fig. 193). When the first harmonic (2) is produced, there will a loop ch end, and a loop in the middle, the column being divided into *four* parts by the alternate loops and nodes (fig. 194). When the second ıonic (3) is produced, the column of air will be divided into *six* equal s by the alternate nodes and loops, and so on (fig. 195). It will be ırked that the successive modes of division of the vibrating column the only ones compatible with the alternate recurrence at equal inals of nodes and loops, and with the occurrence of a loop at each end he pipe.

here are several experiments by which the existence of nodes and can be shown.

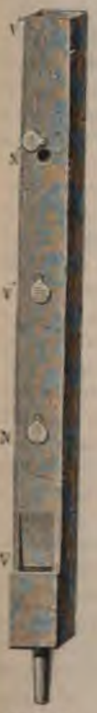


Fig. 196.

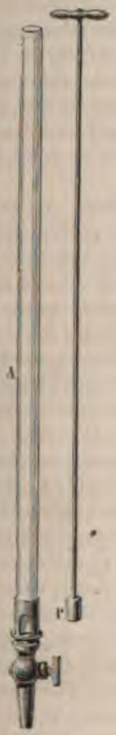


Fig. 197.

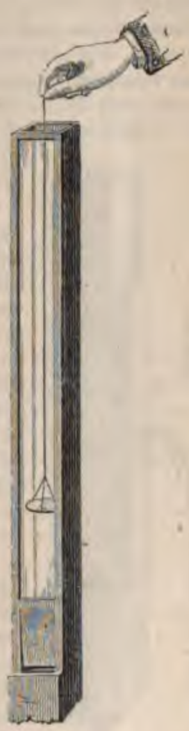


Fig. 198.

If a fine membrane is stretched over a pasteboard ring, and has led on it some fine sand, it can be gradually let down a tube, as in fig. 198. Now suppose the tube to be producing a musical As the membrane descends, it will be set in vibration by the ng air. But when it reaches a node it will cease to vibrate, for he air is at rest. Consequently the grains of sand, too, will be at rest, eir quiescence will indicate the position of the node. On the other hand, when the membrane reaches a loop, that is, a point where t plitude of the vibrations of the air attains a maximum, it will be vi agitated, as will be shown by the agitation of the grains of sand. thus the positions of the loops can be rendered manifest.

(*b*) Again, suppose a pipe to be constructed with holes bored in its sides, and these covered by little doors which can be open shut, as shown in fig. 196. Let us suppose the little doors to be sh the pipe to be caused to produce such a tone that the nodes are at N′ and the loops at V, V′, V″. At the latter points the density is the external air, and consequently if the door at V′ is opened no is produced in the note. At the former points N and N′ there ar nately condensation and rarefaction taking place. If now the N′ is opened, this alternation of density is no longer possible, density at this open point must be the same as that of the exter and consequently N′ becomes a loop and a note yielded by the changed. The change of notes produced by changing the finge the flute is, of course, one form of this ment.

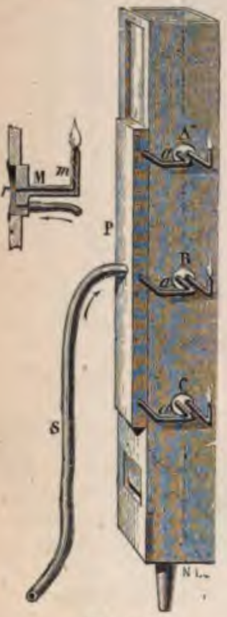


Fig. 199.

(*c*) Suppose A, in fig. 197, to be emitting a certain note, and suppose P plug, fitting the tube, fastened to the en long rod by which it can be forced do tube. Now when the plug is inserted, wl be its position, there will be a node in with it. Consequently, as it is gradually down, the note yielded by the pipe will b changing. But every time it reaches a p which was occupied by a node before its tion, the note becomes the same as th originally yielded. For now the column vibrates in exactly the same manner as before the plug was put in.

(*a*) Fig. 199 shows another mode of illus the same point, which is identical in pr with König's manometric flames. The represents an organ pipe, on one side of is a chest, P, filled with coal gas, by m the tube S. The gas from the chest co in three jets, A, B, C, and is then The manner in which the gas passe the chest to the point of ignition is in the smallest figure, which is an e section of A. A circular hole is bored in the side of the pipe and with a membrane, *r*. A piece of wood is fitted into the hole s leave a small space between it and the membrane. The gas pass the chest, in the direction indicated by the arrow, into the space l the membrane and the piece of wood, and so out of the tube *m* mouth of which it is ignited. Now suppose the pipe to be ca yield its primary note, then as it is an uncovered pipe there ought to be a node at B, its middle point. Consequently there ought to be rapid changes of density at B: these would cause the membrane *r* to vibrate, and thereby blow out the flame *m*, and this is what actually happens. If by increasing the force of the wind the octave to the primary note is produced, B will be a loop, and A and C nodes. Consequently the flames at A and C will now be extinguished, as is, in point of fact, the case. But at B, there being no change of density, the membrane is unmoved, and the flame continues to burn steadily.

By each and all of these experiments it is shown that in a given pipe, whether open or closed, there are always a certain number of nodes, and midway between any two consecutive nodes there is always a *loop* or *ventral segment*.

257. **Explanation of the existence of nodes and loops in a musical pipe.**—The existence of nodes and loops is to be explained by the coexistence in the same pipe of two equal waves travelling in contrary directions.

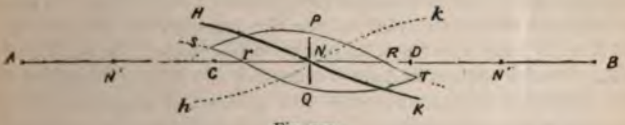


Fig. 200.

Let A be a point from which a series of waves sets out towards B, and let the length of these waves, whether of condensation or rarefaction, be AC, CD, or DB. And let B be the point from which the series of exactly equal waves sets out towards A. It must be borne in mind that in the case of a wave of condensation originating at A, the particles move in the direction A to B, but in a wave of condensation originating at B they move in the direction B to A. Now let us suppose that condensation at C, caused by the wave from A, begins at the same instant that condensation caused by the wave from B begins at D. Consequently, restricting our attention to the particles in the line CD, at any instant the velocities of the particles in CD due to the former wave will be represented by the ordinates of the curve SPRT, while those due to the wave from B will be represented by the co-ordinates of the curve TQ*r*S. Then, since the waves travel with the same velocity and are at C and D respectively at the same instant, we must have, for any subsequent instant, CR equal to D*r*. If, therefore, N is the middle point between C and D, we must have *r*N equal to RN, and consequently PN equal to QN, that is to say, if the particle at N transmitted only one vibration, its motion at each instant would be in the opposite phase to that of its motion if it transmitted only the other vibration. In other words, the particle N will at every instant tend to be moved with equal velocity in opposite directions by the two waves, and therefore will be *permanently* at rest. That point is therefore a *node*. In like manner there is a node at N′ midway between A and C, and also at N″ midway between B and D. In regard to the motion of the remaining particles, it is plain that their respective velocities the (algebraical) sum of the velocities they would at each instant from the waves separately. Hence at the instant indicated by the they are given by the ordinates of the curve HNK. This cu change from instant to instant, and at the end of the time occupie passage of a wave of condensation (or of rarefaction) from C t occupy the position shown by the dotted line hNk. Hence it is that particles near N have but small changes of velocity, whil near C and D experience large changes of velocity.

If the curve HK were produced both ways, it would alwa through N′ and N″; the part, however, between N and N′ woul times be on one side and sometimes on the other side of AB. H the particles between N′ and N have, simultaneously, first a m the direction A to B, and then a motion in the direction B to particles near C having the greatest amplitude of vibrations. near N and N′ there will be alternately the greatest condensat rarefaction.

This explanation applies to the case in which AB is the axis of organ pipe, A being the end where the mouthpiece is situate waves from B have their origin in the reflection of the series o from A. In the particular case considered, the note yielded by is that indicated by 3, that is, the fifth above the octave to the note. A similar explanation can obviously be applied to all oth and whether the end be opened or closed. But in the latter case t of waves from the closed end must co at a point distant from the mouthpie space equal to one-half, or three halves halves, etc. of the length of a wave densation or expansion.

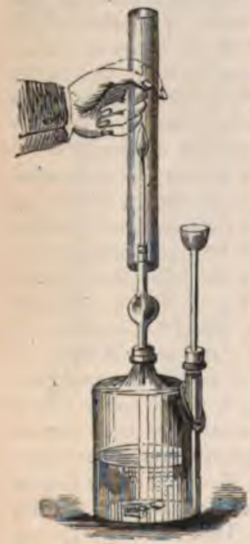


Fig. 201.

258. **Chemical harmonicon.**—The a open tube may be made to give a so means of a luminous jet of hydrogen, c etc. When a glass tube about 12 inch is held over a lighted jet of hydrogen (f a note is produced, which, if the tube certain position, is the fundamental not tube. The sounds, doubtless, arise fr successive explosions produced by the combinations of the atmospheric oxyg the issuing jet of hydrogen. The appa called the *chemical harmonicon*.

The phenomena of the chemical har and of singing flames have been investi Prof. Tyndall, whose *Lectures on Sound* a number of very beautiful experiments subject.

The note depends on the size of t and the length of the tube: with a long tube, by varying the po the jet in the tube, the series of notes in the ratio 1 : 2 : 3 : 4 : 5 is obtained.

If, while the tube emits a certain sound, the voice or the syren (227) be gradually raised to the same height, as soon as the note is nearly in unison with the harmonicon, the flame becomes agitated, jumps up and down, and is finally steady when the two sounds are in unison. If the tone of the syren is gradually heightened, the pulsations again commence; they are the optical expressions of the beats (244) which occur near perfect unison.

If, while the jet burns in the tube and produces a note, the position of the tube is slightly altered, a point is reached at which no sound is heard. If now the voice, or the syren, or the tuning-fork, be pitched at the note produced by the jet, it begins to sing, and continues to sing even after the syren is silent. A mere noise, or shouting at an incorrect pitch, affects the flame, but does not cause it to sing.

259. **Stringed instruments.**—Stringed musical instruments depend on the production of transverse vibrations. In some, such as the piano, the sounds are *constant*, and each note requires a separate string; in others, such as the violin and guitar, the sounds are *varied* by the fingering, and can be produced by fewer strings.

In the piano the vibrations of the strings are produced by the stroke of the *hammer*, which is moved by a series of bent levers communicating with the keys. The sound is strengthened by the vibrations of the air in the sounding board on which the strings are stretched. Whenever a key is struck, a *damper* is raised which falls when the finger is removed from the key and stops the vibrations of the corresponding strings. By means of a *pedal* all the dampers can be simultaneously raised, and the vibrations then last for some time.

The harp is a sort of transition from the instruments with constant to those with variable sounds. Its strings correspond to the natural notes of the scale : by means of the pedals the lengths of the vibrating parts can be changed, so as to produce sharps and flats. The sound is strengthened by the sounding box, and by the vibrations of all the strings harmonic with those played.

In the violin and guitar each string can give a great number of sounds, according to the length of the vibrating part, which is determined by the pressure of the fingers of the left hand while the right hand plays the bow, or the strings themselves. In both these instruments the vibrations are communicated to the upper face of the sounding box, by means of the bridge over which the strings pass. These vibrations are communicated rom the upper to the lower face of the box, either by the sides or by an termediate piece call the *sound post*. The air in the interior is set in bration by both faces, and the strengthening of the sound is produced f all these simultaneous vibrations. The value of the instrument con-ts in the perfection with which all possible sounds are intensified, hich depends essentially on the quality of the wood, and the relative rangement of the parts.

260. **Wind instruments.**—All wind instruments may be referred to

the different types of sounding tubes which have been described. In some, such as the organ, the notes are *fixed*, and require a separate pipe for each note; in others the notes are *variable*, and are produced by only one tube: the flute, horn, etc. are of this class.

In the organ the pipes are of various kinds, namely, mouth pipes, open and stopped, and reed pipes with apertures of various shapes. By means of *stops* the organist can produce any note by both kinds of pipe.

In the *flute*, the mouthpiece consists of a simple lateral circular aperture; the current of air is directed by means of the lips, so that it grazes the edge of the aperture. The holes at different distances are closed either by the fingers or by keys; when one of the holes is opened, a loop is produced in the corresponding layer of air, which modifies the distribution of nodes and loops in the interior, and thus alters the note. The whistling of a key is similarly produced.

The *pandæan pipe* consists of tubes of different sizes corresponding to the different notes of the gamut.

In the trumpet, the horn, the trombone, cornet-à-piston, and ophicleide the lips form the reed, and vibrate in the mouthpiece. In the *horn* different notes are produced by altering the distance of the lips. In the *trombone*, one part of the tube slides within the other, and the performer can alter at will the length of the tube, and thus produce higher or lower notes. In the *cornet-à-piston*, the tube forms several convolutions; pistons placed at different distances can, when played, cut off communication with other parts of the tube, and thus alter the length of the vibrating column of air.

CHAPTER V.

VIBRATIONS OF RODS, PLATES, AND MEMBRANES.

261. **Vibrations of rods.**—Rods and narrow plates of wood, of glass and especially of tempered steel, vibrate in virtue of their elasticity; lik strings they have two kinds of vibrations, longitudinal and transverse The latter are produced by fixing the rods at one end, and passing a bow over the free part. Longitudinal vibrations are produced by fixing th rod at any part, and rubbing it in the direction of its length with a piec of cloth sprinkled with resin. But in the latter case the sound is onl produced when the point of the rod at which it has been fixed is som aliquot part of its length, as a half, a third, or a quarter.

It is shown by calculation that *the number of transverse vibrations ma in a given time by rods and thin plates of the same kind is directly as the thickness, and inversely as the square of their length.* The width of the pla does not affect the number of vibrations. A wide plate, however, requir a greater force to set it in motion than a narrow one. It is, of cours understood that one end of the vibrating plate is held firmly.

tic rods of the same kind *the number of longitudinal vibrations ly as their length, whatever be the diameter and form of their e section.*

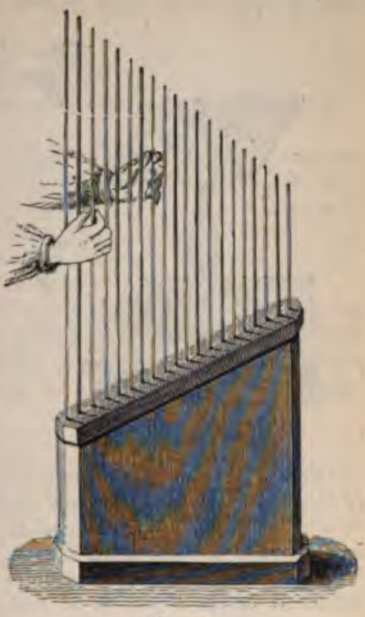


Fig. 202.

02 represents an instru- vented by Marloye, and s *Marloye's harp*, based on itudinal vibration of rods. sts of a solid wooden in which are fixed twenty rods, some coloured and hite. They are of such a at the white rods give the scale, while the coloured e the half notes, and com- chromatic scale. The in- is played by rubbing the he direction of their length, the finger and thumb, ve been previously covered vdered resin. The notes l resemble those of a pan- e.

uning-fork, the *triangle*, *ical-boxes* are examples of verse vibrations of rods. al-boxes small plates of different dimensions are a rod, like the teeth of a A cylinder, whose axis is this rod, and whose surface is studded with steel teeth, arranged ain order, is placed near the plates. By means of a clockwork he cylinder rotates, and the teeth striking the steel plate in vibration, producing a tune, which depends on the arrange- he teeth on the cylinder.

ibrations of plates.—In order to make a plate vibrate, it is he centre (fig. 203), and a bow rapidly drawn across one of the r else it is fixed at any point of its surface, and caused to vibrate ly drawing a string covered with resin against the edges of a ole (fig. 204).

ing plates contain nodal lines (251), which vary in number and according to the form of the plates, their elasticity, the mode of , and the number of vibrations. These nodal lines may be ible by covering the plate with fine sand before it is made to As soon as the vibrations commence, the sand leaves the parts, and accumulates on the nodal lines, as seen in figs. 203

sition of the nodal lines may be determined by touching the which it is desired to produce them. Their number increases with the number of vibrations, that is, as the note given by the plates i higher. The nodal lines always possess great symmetry of form, and th same form is always produced on the same plate under the same con ditions. They were discovered by Chladni.

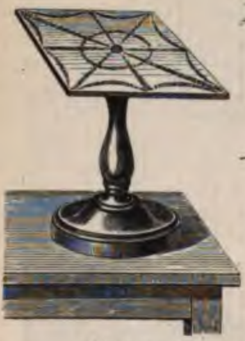


Fig. 203.

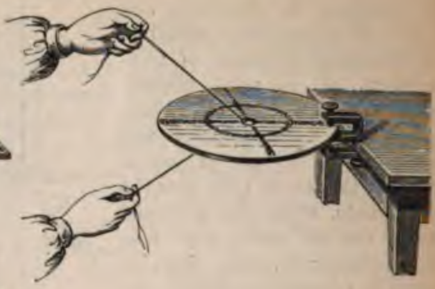


Fig. 204.

The vibrations of plates are governed by the following law :—*In plates of the same kind and shape, and giving the same system of nodal lines, the number of vibrations per second is directly as the thickness of the plates, and inversely as their area.*

Gongs and *cymbals* are examples of instruments in which sounds are produced by the vibration of metallic plates. The *glass harmonicon* depends on the vibrations of glass plates.

263. **Vibrations of membranes.**—In consequence of their inflexibility, membranes cannot vibrate unless they are stretched, like the skin of a drum. The sound they give is more acute in proportion as they are smaller and more tightly stretched. To obtain vibrating membranes, Savart fastened gold-beater's skin on wooden frames.

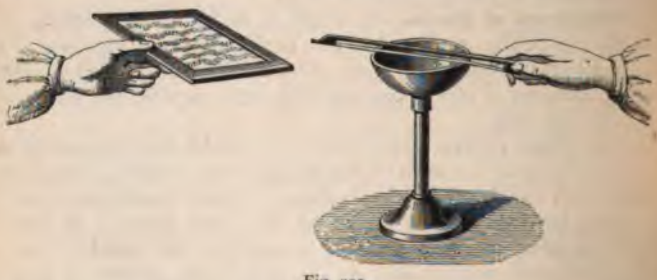


Fig. 205.

In the *drum*, the skins are stretched on the ends of a cylindrical box When one end is struck, it communicates its vibrations to the interna column of air, and the sound is thus considerably strengthened. The cords stretched against the lower skin strike against it when it vibrates, and produce the sound characteristic of the drum.

Membranes either vibrate by direct percussion, as in the drum, or they may be set in vibration by the vibrations of the air, as Savart has observed, provided these vibrations are sufficiently intense. Fig. 205 shows a membrane vibrating under the influence of the vibrations in the air caused by a sounding bell. Fine sand strewn on the membrane shows the formation of nodal lines just as upon plates.

There are numerous instances in which solid bodies are set in vibration by the vibrations of the air. The condition most favourable for the production of this phenomenon is, that the body to be set in vibration is under such conditions that it can readily produce vibrations of the same duration as those transmitted to it by the air. The following are some of these phenomena :

If two violoncello strings tuned in unison are stretched on the same sound-box, as soon as one of them is sounded, the other is set in vibration. This is also the case if the interval of the strings is an octave, or a perfect fifth. A violin string may also be made to vibrate by sounding a tuning-fork.

Two large glasses are taken of the same shape, and as nearly as possible of the same dimensions and weight, and are brought in unison by pouring into them proper quantities of water. If now one of them is sounded, the other begins to vibrate, even if it is at some distance, but if water be added to the latter, it ceases to vibrate.

Breguet found that if two clocks, whose time was not very different, were fixed on the same metallic support, they soon attained exactly the same time.

Membranes are eminently fitted for taking up the vibrations of the air, on account of their small mass, their large surface, and the readiness with which they subdivide. With a pretty strong whistle, nodal lines may be produced in a membrane stretched on a frame, even at the end of a large room.

The phenomenon so easily produced in easily-moved bodies is also found in large and less elastic masses ; all the pillars and walls of a church vibrate more or less while the bells are being rung.

CHAPTER VI.

GRAPHICAL METHOD OF STUDYING VIBRATORY MOVEMENTS.

264. **M. Lissajous' method of making vibrations apparent.**—The ethod of M. Lissajous exhibits the vibratory motion of bodies either irectly or by projection on a screen. It has also the great advantage at the vibratory motions of two sounding bodies may be compared *ithout the aid of the ear*, so as to obtain the exact relation between them.

This method, which depends on the persistence of visual sensations the retina, consists in fixing a small mirror on the vibrating body, so a

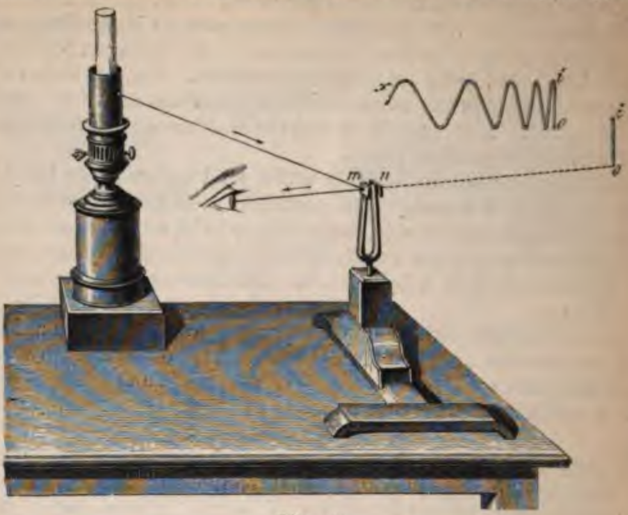


Fig. 206.

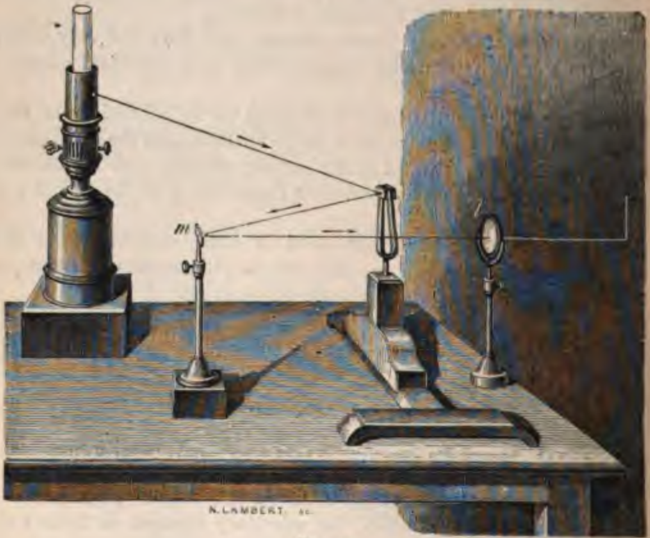


Fig. 207.

vibrate with it, and impart to a luminous ray a vibratory motion similar its own.

M. Lissajous uses tuning-forks, and fixes to one of the prongs a small metallic mirror, *m* (fig. 206), and to the other a counterpoise, *n*, which is necessary to make the tuning-fork vibrate regularly for a long time. At a few yards' distance from the mirror there is a lamp surrounded by a dark chimney, in which is a small hole, giving a single luminous point. The tuning-fork being at rest, the eye is placed so that the luminous point is seen at *o*. The tuning-fork is then made to vibrate, and the image elongates so as to form a persistent image, *oi*, which diminishes in proportion as the amplitude of the oscillation decreases. If, during the oscillation of the mirror, it is made to rotate by rotating the tuning-fork on its axis, a sinuous line, *oix*, is produced instead of the straight line *oi*. These different effects are explained by the successive displacements of the luminous pencil, and by the duration of these luminous impressions on the eye after the cause has ceased, a phenomenon to which we shall revert in treating of vision.

If, instead of viewing these effects directly they are projected on the screen, the experiment is arranged as shown in fig. 207, the pencil reflected from the vibrating mirror is reflected a second time from a fixed mirror, *n*, which sends it towards an achromatic lens, *l*, placed so as to project the images on the screen.

265. **Combination of two vibratory motions in the same direction.** —M. Lissajous has resolved the problem of the optical combination of two vibratory motions—vibrating at first in the same direction, and then at right angles to each other.

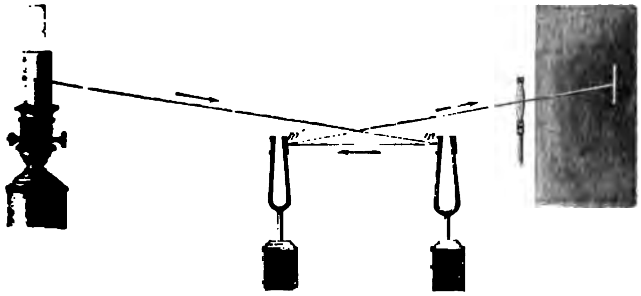


Fig. 208.

Fig. 208 represents the experiment as arranged for combining two parallel motions. Two tuning-forks provided with mirrors are so arranged that the light reflected from one of them reaches the other, which is almost parallel to it, and is then sent towards a screen after having passed through a lens.

If now the first tuning-fork alone vibrates, the image on the screen is the same as in figure 208; but if they both vibrate, supposing they are in unison, the elongation increases or diminishes according as the simultaneous motion imparted to the image by the vibrations of the mirrors do or do not coincide.

s their position of equilibrium in the same time, , the image attains its maximum ; and the image hey pass at the same time but in opposite direc- wo extreme cases the amplitude of the image time which elapses between the exact instant at ass through their position of rest respectively he time of a double vibration is called a *differ-* ion.

exactly in unison, the luminous appearance o gradual diminution of length in proportion a ation diminishes ; but if the pitch of one is ver de of the image varies periodically, and, whil he imperfect harmony are distinctly heard, th pulsations of the image.

tion of two vibratory motions at right angle tical combination of two rectangular vibrator own in the figure 209, that is, by means of tw h is horizontal and the other vertical, and bot

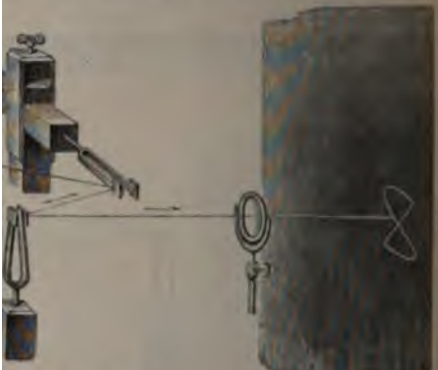


Fig. 209.

f the horizontal fork first vibrates alone, a hor s seen on the screen, while the vibration of th l image. If both tuning-forks vibrate simul s combine, and the reflected pencil describes a ve, the form of which depends on the number of ning-forks in a given time. This curve give paring the number of vibrations of two soundin

inous image on the screen when the tuning-fork en the number of vibrations is equal.

ch curve indicate the differences of phase betwe f the curve is determined by the difference of s exactly the same form when the tuning-fork

ted that the ampl the same ratio.

Fig.

ks are not quite in nd the curve passe

Fig.

s the different a between the tuni

the numbers of their vibrations are as 1 : 2; and fig. 212 gives the ser of curves when the numbers of the vibrations are as 3 : 4.

It will be seen that the curves are more complex when the ratios of th numbers of vibrations are less simple. M. Lissajous has examined thes curves theoretically (*Annales de Physique et de Chimie*, 1857), and ha calculated their general equations.

When these experiments are made with a Duboscq's photo-electric apparatus instead of an ordinary lamp, the phenomena are remarkabl brilliant.

267. **Léon Scott's Phonautograph.**—This beautiful apparatus pos sesses the great advantage of being able to register not only the vibra tions produced by solid bodies, but also those produced by wind instr ments, by the voice in singing, and even by any noise whatsoever, fo

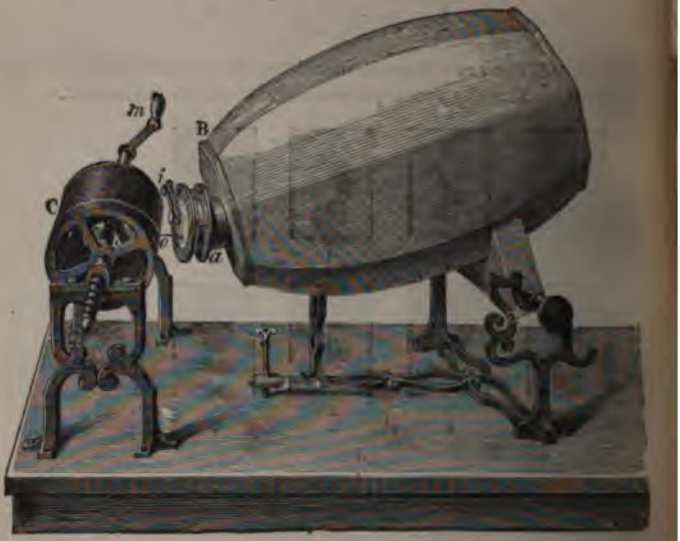


Fig. 213.

instance, that of thunder, or the report of a cannon. It consists of a ellipsoidal barrel, AB, about a foot and a half long and a foot in i greatest diameter, made of plaster of Paris. The end A is open, but th end B is closed by a solid bottom, to the middle of which is fitted a bra tube, *a*, bent at an elbow and terminated by a ring on which is fixed flexible membrane which by means of a second ring can be stretched the required amount. Near the centre of the membrane, fixed by sealin wax, is a hog's bristle which acts as a style, and, of course, shares t movements of the membrane. In order that the style might not be a *node*, M. Scott fitted the stretching ring with a movable piece, *i*, whi he calls a subdivider, and which, being made to touch the membrane fi at one point and then at another, enables the experimenter to alter the arrangements of the nodal lines at will. By means of the subdivider the point is made to coincide with a loop, that is, a point where the vibrations of the membrane are at a maximum.

When a sound is produced near the apparatus, the air in the ellipsoid, the membrane, and the style will vibrate in unison with it, and it only remains to trace on a sensitive surface the vibrations of the style, and to fix them. For this purpose there is placed in front of the membrane a copper cylinder, C, turning round a horizontal axis by means of a handle, at. On the prolonged axis of the cylinder a screw is cut which works in a nut; consequently, when the handle is turned, the cylinder gradually advances in the direction of its axis. Round the cylinder is wrapped a sheet of paper, covered with a thin layer of lampblack.

The apparatus is used by bringing the prepared paper into contact with the point of the style, and then setting the cylinder in motion round its axis. So long as no sound is heard the style remains at rest, and merely removes the lampblack along a line which is a helix on the cylinder, but which becomes straight when the paper is unwrapped. But when a sound is heard, the membrane and the style vibrate in unison, and the line traced out is no longer straight, but undulates; each undulation corresponding to a double vibration of the style. Consequently, the figures thus obtained faithfully denote the number, amplitude, and isochronism of the vibrations.

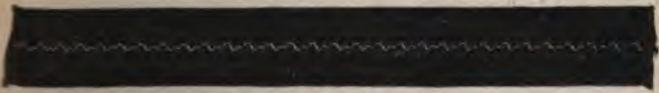


Fig. 214.

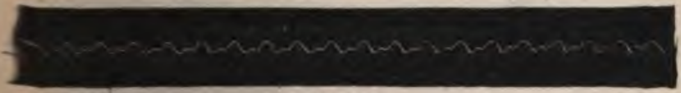


Fig. 215.

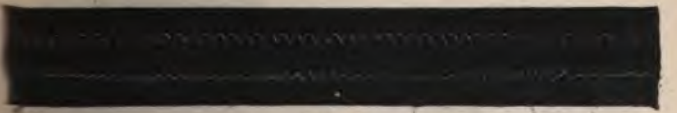


Fig. 216.

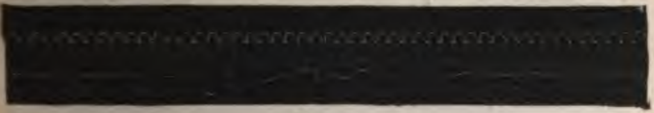


Fig. 217

Fig. 214 shows the trace produced when a simple note is sung, and strengthened by means of its upper octave. The latter note is represen by the curve of lesser amplitude. Fig. 215 represents the sound produ jointly by two pipes whose notes differ by an octave. Fig. 216 in lower line represents the rolling sound of the letter R when pronoun with a ring; and fig. 217 on its lower line represents the sound produ by a tin plate when struck with the finger.

The upper lines of figs. 216 and 217 are the same, and represent perfectly isochronous vibrations of a tuning-fork placed near the ellipso These lines were traced by a fine point on one branch of the fork, wh was thus found to make exactly 500 vibrations per second. In con quence, each undulation of the upper line corresponds to the $\frac{1}{500}$th part a second; and thus these lines become very exact means of measuri short intervals of time. For example, in fig. 216, each of the separ shocks producing the rolling sound of the letter R corresponds to ab 18 double vibrations of the tuning-fork, and consequently lasts about or about $\frac{1}{28}$th of a second.

268. **König's manometric flames.**—König's method consists in tran mitting the movement of the sonorous waves which constitute a sound gas flames, which, by their pulsations, indicate the nature of the sound For this purpose a metallic capsule, represented in section at A, fig. 21

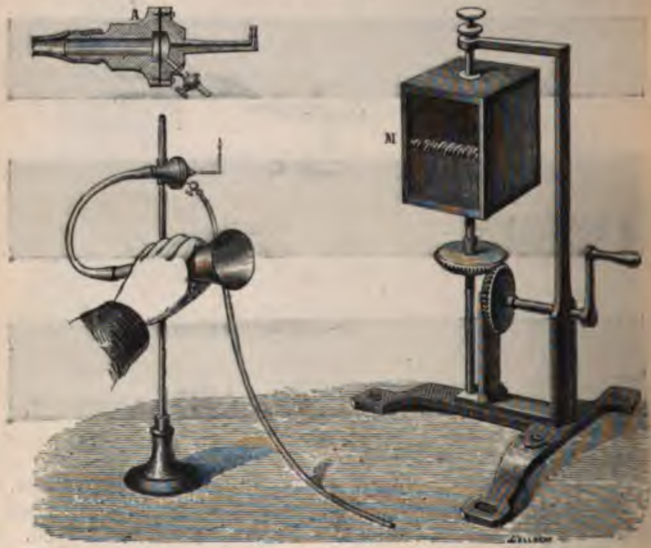
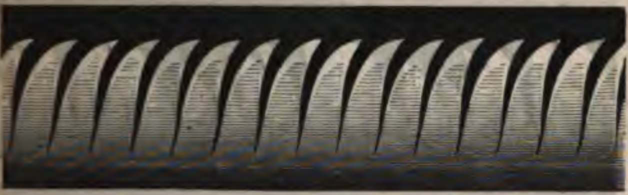


Fig. 218.

is divided into two compartments by a thin membrane of caoutchouc; the right of the figure is a gas jet, and below it a tube conveying coal g on the left is a tubulure, to which may be attached a caoutchouc t The other end of this may be placed at the node of an organ pipe (2 it terminates in a mouth-piece, in front of which a given note may be ng ; this is the arrangement represented in fig. 218.

When the sound waves enter the capsule by the mouth-piece and the

Fig. 219.



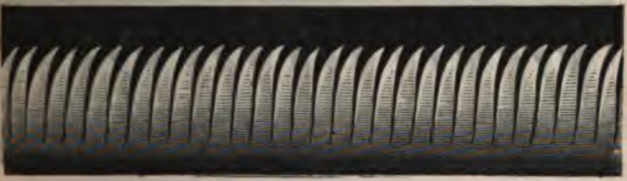
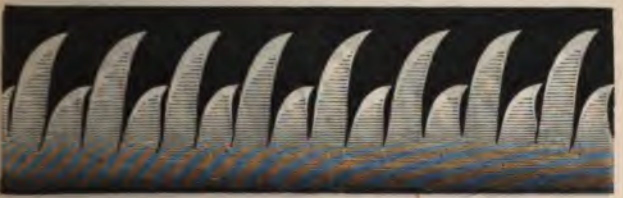


Fig. 220.

ube, the membrane yielding to the condensation and rarefaction of the waves, the coal gas in the compartment on the right is alternately con-

Fig. 221.



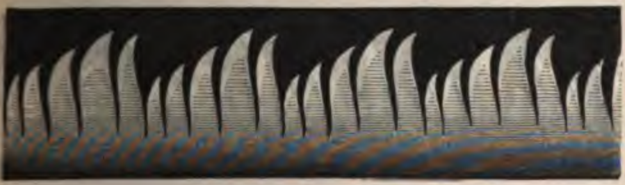
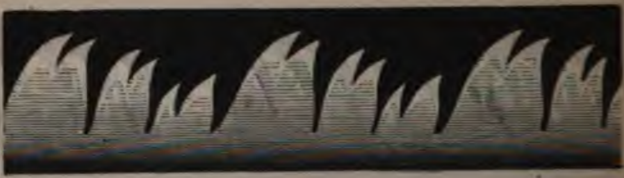


Fig. 222.

racted and expanded, and hence are produced alternations in the length f the flame, which are, however, scarcely perceptible when the flame is bserved directly. But to render them distinct they are received on a mirror with four faces, M, which may be turned by two cog-wheels handle. As long as the flame burns steadily there appears in the when turned, a continuous band of light. But if the capsule is

Fig. 223.



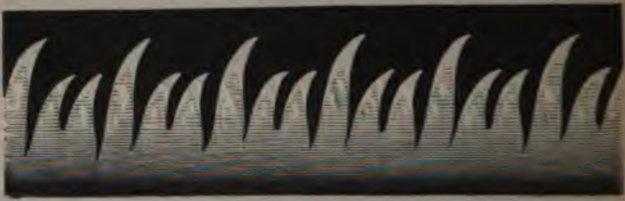
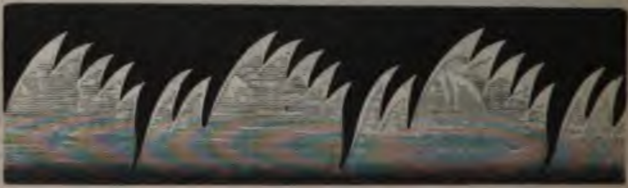


Fig. 224.

with a sounding tube yielding the fundamental note, the image of flame takes the form represented in figure 219, and that of figure the sound yields the octave. If the two sounds reach the capsule

Fig. 225.



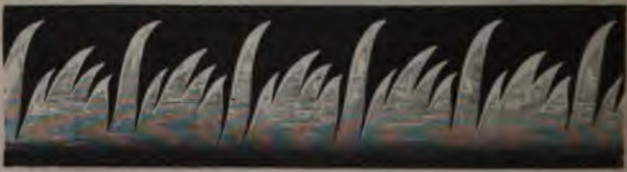


Fig. 226.

taneously the flame has the appearance of fig. 221 : in that case, the tube leading to the capsule must be connected by a T-pipe with sounding tubes, one giving the fundamental note, and the other re. If one gives the fundamental note and the other the third, the e has the appearance of figure 222.

the vowel E be sung in front of the mouth-piece first upon *ut*, and upon ut_3, the turning mirror gives the flames represented in 223 and 224; and by singing the vowel O on the same notes the 225 and 226.

BOOK VI.

ON HEAT.

CHAPTER I.

PRELIMINARY IDEAS. THERMOMETERS.

269. **Heat. Hypothesis as to its nature.**—In ordinary language the term *heat* is not only used to express a particular sensation, but also to describe that particular state or condition of matter which produces this sensation. Besides producing this sensation, heat acts variously upon bodies; it melts ice, boils water, makes metals red-hot, produces electrical currents, decomposes compound bodies, and so forth.

Two theories as to the cause of heat are current at the present time; these are the *theory of emission* and the *theory of undulation*.

On the first theory, heat is caused by a subtle imponderable fluid, which surrounds the molecules of bodies, and which can pass from one body to another. These *heat atmospheres*, which thus surround the molecules, exert a repelling influence on each other, in consequence of which heat acts in opposition to the force of cohesion. The entrance of this substance into our bodies produces the sensation of warmth, its egress the sensation of cold.

On the second hypothesis the heat of a body is caused by an extremely rapid oscillating or vibratory motion of its molecules; and the hottest bodies are those in which the vibrations have the greatest velocity and the greatest amplitude. At any given time the whole of the molecules of a body possess a sum of *vis viva* which is the heat they contain. To increase their temperature is to increase their vis viva, to lower their temperature is to decrease their vis viva. Hence, on this view, heat is not a substance but a condition of matter, and a condition which can be transferred from one body to another. When a heated body is placed in contact with a cooler one the former cedes more molecular motion than it receives; but the loss of the former is the equivalent of the gain of the latter.

It is also assumed that there is an imponderable elastic ether, which pervades all matter and infinite space. A hot body sets this in rapid vibration, and the vibrations of this ether being communicated to material objects set them in more rapid vibration, that is, increase their mperature. Here we have an analogy with sound; a sounding body in a state of vibration, and its vibrations are transmitted by atmoheric air to the auditory apparatus in which is produced the sensation of und.

This hypothesis as to the nature of heat is now admitted by the most stinguished physicists. It affords a better explanation of all the phenoena of heat than any other theory; and it reveals an intimate connecn between heat and light. It will be subsequently seen that by the ction of bodies against each other an indefinite quantity of heat is oduced. Experiment has shown that there is an exact equivalence tween the motion thus destroyed and the heat produced. These and any other facts are utterly inexplicable on the assumption that heat a substance, and not a form of motion.

In what follows, however, the phenomena of heat will be considered, as r as possible, independently of either hypothesis; but we shall subseuently return to the reasons for the adoption of the latter hypothesis.

270. **General effects of heat.**—The general effects of heat upon bodies ay be classed under three heads. One portion is expended in raising e temperature of the body, that is, in increasing the vis viva of its olecules. In the second place, the molecules of bodies have a certain ttraction for each other, owing to which is due their relative positions; ence a second portion of heat is consumed in augmenting the amplide of the oscillations by which an increase of volume is produced, or completely altering the relative positions of the molecules by which change of state is effected. These two effects are classed as *internal ork.* Thirdly, since bodies are surrounded by atmospheric air which xerts a certain pressure on their surface, this has to be overcome or fted through a certain distance. The heat or work required for this s called the *external work.*

If Q units of heat are imparted to a body, and if A be the quantity of eat which is equivalent to the unit of work; then if W is the amount f heat which serves to increase the temperature, I that required to alter he position of the molecules, and if L be the equivalent of the external ork, then

$$Q = A\,(W + I + L).$$

271. **Expansion.**—All bodies expand by the action of heat. As a general rule, gases are the most expansible, then liquids, and lastly, solids.

In solids which have definite figures, we can either consider the expansion in one dimension, or the *linear* expansion; in two dimensions, the *superficial* expansion; or in three dimensions, the *cubical* expansion or the expansion of volume, although one of these never takes place without the other. As liquids and gases have no definite figures, the expansions of volume have in them alone to be considered.

To show the linear expansion of solids, the apparatus represented in fig. 227 may be used. A metal rod, A, is fixed at one end by a screw B, while the other end presses against the short arm of an index, K, which moves on a scale. Below the rod there is a sort of cylindr lamp in which alcohol is burned. The needle K is at first at the point, but as the rod becomes heated it expands, and moves the nee along the scale.

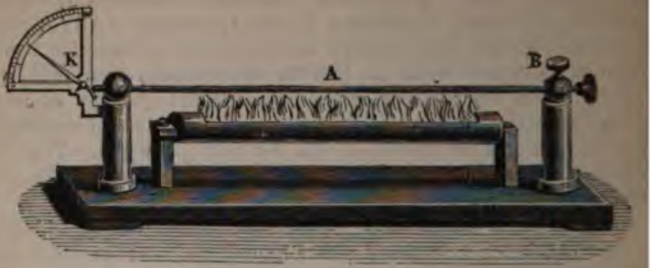


Fig. 227.

The cubical expansion of solids is shown by a *Gravesande's* ring. consists of a brass ball *a* (fig. 228), which at the ordinary tempera passes freely through a ring, *m*, almost of the same diameter. But w the ball has been heated, it expands and no longer passes through ring.

In order to show the expansion of liquids, a large glass bulb provi

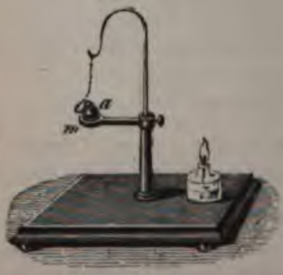


Fig. 228.

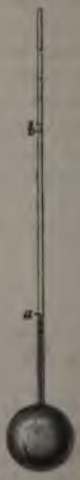


Fig. 229.

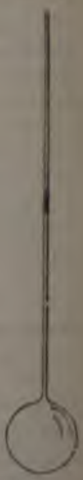


Fig. 230.

with a capillary stem is used (fig. 229). If the bulb and a part o stem contain some coloured liquid, the liquid rapidly rises in the when heat is applied, and the expansion thus observed is far gr than in the case of solids.

The same apparatus may be used for showing the expansion of gases. Being filled with air, a small thread of mercury is introduced into the apillary tube to serve as index (fig. 230). When the globe is heated in he slightest degree, even by approaching the hand, the expansion is so reat that the index is driven to the end of the tube, and is finally xpelled. Hence, even for a very small degree of heat, gases are highly xpansible.

In these different experiments the bodies contract on cooling, and hen they have attained their former temperature they resume their riginal volume. Certain metals, however, especially zinc, form an xception to this rule, and it appears to be also the case with some kinds f glass.

MEASUREMENT OF TEMPERATURE. THERMOMETRY.

272. **Temperature.**—The *temperature* or hotness of a body, independently of any hypothesis as to the nature of heat, may be defined as being he greater or less extent to which it tends to impart sensible heat to other bodies. The *temperature* of a body must not be confounded with the *quantity of heat* it possesses; a body may have a high temperature and yet have a very small quantity of heat, and conversely a low temperature and yet possess a large amount of heat. If a cup of water be taken from a bucketful, both will indicate the same temperature, yet the quantities they possess will be different. This subject of the quantity of heat will be afterwards more fully explained in the chapter on Specific Heat.

273. **Thermometers.**—*Thermometers* are instruments for measuring temperatures. Owing to the imperfections of our senses we are unable to measure temperatures by the sensation of heat or cold which they produce in us, and for this purpose recourse must be had to the physical action of heat on bodies. These actions are of various kinds, but the expansion of bodies has been selected as the easiest to observe. But heat also produces electrical phenomena in bodies; and on these the most delicate methods of observing temperatures have been based, as we shall see in a subsequent chapter.

Liquids are best suited for the construction of thermometers—the expansion of solids being too small, and that of gases too great. Mercury and alcohol are the only liquids used—the former because it only boils at a very high temperature, and the latter because it does not solidify at he greatest known cold.

The mercurial thermometer is the most extensively used. It consists of a capillary glass tube, at the end of which is blown the *bulb*, a cylinrical or spherical reservoir. Both the bulb and a part of the stem are illed with mercury, and the expansion is measured by a scale graduated ither on the stem itself, or on a frame to which it is attached.

Besides the manufacture of the bulb, the construction of the thermoeter comprises three operations: the *calibration* of the tube, or its ivision into parts of equal capacity, the introduction of the mercury into e reservoir, and the graduation.

274. **Division of the tube into parts of equal capacity.**— indications of the thermometer are only correct when the divisions scale correspond to equal expansions of the mercury in the reserv scale must be graduated so as to indicate parts of equal capacity tube. If the tube were quite cylindrical, and of the same di throughout, it would only be necessary to divide it into equal l But as the diameter of glass tubes is usually greater at one en another, parts of equal capacity in the tube are represented by u lengths of the scale.

In order, therefore, to select a tube of uniform calibre, a thr mercury about an inch long is introduced into the capillary tub moved in different positions in the tube, care being taken to kee the same temperature. If the thread is of the same length in part of the tube, it shows that the capacity is everywhere the sam if the thread occupies different lengths the tube is rejected, and a one sought.

275. **Filling the thermometer.**—In order to fill the thermomet mercury, a small funnel, C (fig. 231), is blown on at the top, and i with mercury ; the tube is then slightly in and the air in the bulb expanded by hea with a spirit lamp. The expanded air p escapes by the funnel, and on cooling, which remains contracts, and a portion mercury passes into the bulb D. The then again warmed, and allowed to cool, quantity of mercury enters, and so on, u bulb and part of the tube are full of m The mercury is then heated to boilin mercurial vapours in escaping carry wit the air and moisture which remain in th The tube, being full of the expanded n and of mercurial vapour, is hermetically at one end. When the thermometer is c mercury ought to fill the bulb and a por the stem.

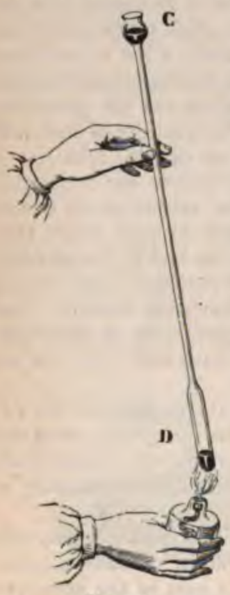


Fig. 231.

276. **Graduation of the thermometer** thermometer being filled, it requires to duated, that is, to be provided with a s which variations of temperature can be r And, first of all, two points must be fixed represent identical temperatures and can be easily produced.

Experiment has shown that ice alway at the same point whatever be the degree of heat, and that distille under the same pressure, and in a vessel of the same kind, alwa at the same temperature. Consequently, for the first fixed point, the temperature of melting ice has been taken ; and for a secon

, the temperature of boiling water in a metallic vessel under the al atmospheric pressure of 760 millimeters.

is interval of temperature, that is, the range from zero to the boiling , is taken as the unit for comparing temperatures ; just as a certain h, a foot or a yard for instance, is used as a basis for comparing hs.

'. **Determination of the fixed points.**—To obtain zero, snow or ded ice is placed in a vessel, in the bottom of which is an aperture hich water escapes (fig. 232). The bulb part of the stem of the thermometer are rsed in this for about a quarter of an hour, a mark made at the level of the mercury a represents zero.

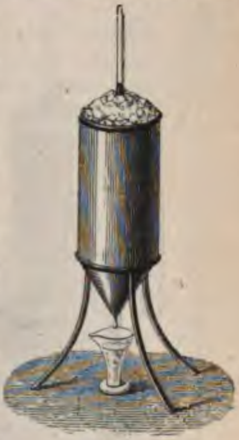


Fig. 232.

e second fixed point is determined by s of the apparatus represented in the s 233 and 234, of which fig. 234 represents tical section. In both, the same letters nate the same parts. The whole of the atus is of copper. A central tube, A, open th ends, is fixed on a cylindrical vessel ining water; a second tube, B, concentric the first, and surrounding it, is fixed on ame vessel, M. In this second cylinder, is closed at both ends, there are three ures, *a*, E, D. A cork, in which is the ometer *t*, fits in *a*. To E a glass tube, ining mercury, is attached, which serves as nometer for measuring the pressure of the vapour in the apparatus. an escape tube for the vapour and condensed water.

e apparatus is placed on a furnace and heated till the water boils; the ur produced in M rises in the tube A, and passing through the two in the direction of the arrows, escapes by the tubulure D. The ometer *t* being thus surrounded with vapour, the mercury expands, when it has become stationary, the point at which it stops is marked. s the point sought for. The object of the second case, B, is to avoid ooling of the central tubulure by its contact with the air.

e determination of the point 100 (see next article) would seem to re that the height of the barometer during the experiment should o millimeters, for when the barometric height is greater or less than quantity, water boils either above or below 100 degrees. But the 100 may always be exactly obtained, by making a correction in- ced by M. Biot. He found that, for every 27 millimeters' difference ght of the barometer, there was a difference in the boiling point of ree. If, for example, the height of the barometer is 778—that is, llimeters, or two-thirds of 27, above 760—water would boil at 100 es and two-thirds. Consequently, $100\frac{2}{3}$ would have to be marked point at which the mercury stops.

Gay-Lussac observed that water boils at a somewhat higher temperature in a glass than in a metal vessel: and as the boiling point is raised by any salts which are dissolved, it has been assumed that it was necessary to use a metal vessel and distilled water in fixing the boiling point. M. Rudberg has, however, shown that these latter precautions are superfluous. The nature of the vessel, and salts dissolved in ordinary water, influence the temperature of boiling water, but not that of the vapour which is formed. That is to say, that if the temperature of boiling water from any of the above causes is higher than 100 degrees, the temperature of the vapour does not exceed 100, provided the pressure is not more than 760 millimeters. Consequently, the higher point may be determined in a vessel of any material, provided the thermometer is quite surrounded by vapour, and does not dip in the water.

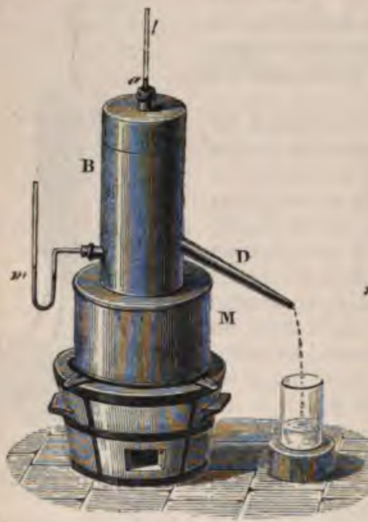


Fig. 233.

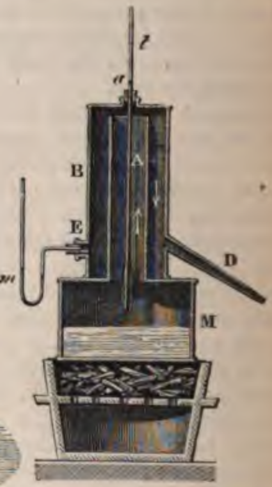


Fig. 234.

Even with distilled water, the bulb of the thermometer must not dip in the liquid; for it is only the upper layer that really has the temperature of 100 degrees, since the temperature increases from layer to layer towards the bottom in consequence of the increased pressure.

278. **Construction of the scale.**—Just as the foot-rule which is adopted as the unit of comparison for length is divided into a number of equal divisions called inches for the purpose of having a smaller unit of comparison, so likewise the unit of comparison of temperatures, the range from zero to the boiling point, must be divided into a number of parts of equal capacity called *degrees*. There are three modes in which this is done. On the Continent, and more especially in France, this space is divided into 100 parts, and this division is called the *Centigrade* or *Celsius*

the latter being the name of the inventor. The Centigrade ther-er is almost exclusively adopted in foreign scientific works, and as is gradually extending in this country, it has been and adopted in this book.

degrees are designated by a small cipher placed a little on the right of the number which marks the temperature, indicate temperatures below zero the minus sign is before them. Thus, $-15°$ signifies 15 degrees below

ccurate thermometers the scale is marked on the stem fig. 235). It cannot be displaced, and its length remains as glass has very little expansibility. The graduation is d by covering the stem with a thin layer of wax, and then ig the divisions of the scale, as well as the corresponding rs, with a steel point. The thermometer is then exposed out ten minutes to the vapours of hydrofluoric acid, which s the glass where the wax has been removed. The rest wax is then removed, and the stem is found to be per-tly etched.

des the *Centigrade* scale two others are frequently used *renheit's scale* and *Réaumur's scale*.

Réaumur's scale the fixed points are the same as on the rade scale, but the distance between them is divided into grees, instead of into 100. That is to say, 80 degrees nur are equal to 100 degrees Centigrade; one degree nur is equal to $\frac{100}{80}$ or $\frac{5}{4}$ of a degree Centigrade, and one Centigrade equals $\frac{80}{100}$ or $\frac{4}{5}$ degrees Réaumur. Conse-y, to convert any number of Réaumur degrees into Centi-degrees (20 for example), it is merely necessary to multiply by $\frac{5}{4}$ (which gives 25). Similarly, Centigrade degrees are rted into Réaumur by multiplying them by $\frac{4}{5}$.

thermometric scale invented by Fahrenheit in 1714 is uch used in England, and also in Holland and North ca. The higher fixed point is like that of the other scales, mperature of boiling water, but the null point or zero is the tem-re obtained by mixing equal weights of sal-ammoniac and snow, he interval between the two points is divided into 212 degrees. ero was selected because the temperature was the lowest then i, and was thought to represent absolute cold. When Fahrenheit's ometer is placed in melting ice it stands at 32 degrees, and, there-100 degrees on the Centigrade scale are equal to 180 degrees on the nheit scale, and thus 1 degree Centigrade is equal to $\frac{9}{5}$ of a degree nheit, and inversely 1 degree Fahrenheit is equal to $\frac{5}{9}$ of a degree rade.

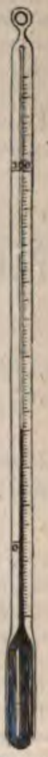


Fig. 235.

be required to convert a certain number of Fahrenheit degrees (95 mple) into Centigrade degrees, the number 32 must first be sub-l, in order that the degrees may count from the same part of the The remainder in the example is thus 63, and as 1 degree Fahrenheit is equal to $\frac{5}{9}$ of a degree Centigrade, 63 degrees are equal to $63 + \frac{5}{9}$ or 35 degrees Centigrade.

If F be the given temperature in Fahrenheit degrees and C the corresponding temperature in Centigrade degrees, the former may be converted into the latter by means of the formula

$$(F. = 32)\ \tfrac{5}{9} = C,$$

and conversely, Centigrade degrees may be converted into Fahrenheit by means of the formula

$$\tfrac{9}{5}C. + 32 = F.$$

These formulæ are applicable to all temperatures of the two scales, provided the signs are taken into account. Thus, to convert the temperature of 5 degrees Fahrenheit into Centigrade degrees, we have

$$(5 - 32)\tfrac{5}{9} = \frac{-27 + 5}{9} = -15\ C.$$

In like manner we have, for converting Réaumur into Fahrenheit degrees, the formula

$$\tfrac{9}{4}R. + 33 = F,$$

and conversely, for changing Fahrenheit into Réaumur degrees, the formula

$$(F. - 32)\ \tfrac{4}{9} = R.$$

279. **Displacement of zero.**—Thermometers, even when constructed with the greatest care, are subject to a source of error which must be taken into account: this is, that in course of time the zero tends to rise, the displacement sometimes extending to as much as 2 degrees; so that when the thermometer is immersed in melting ice it no longer sinks to zero.

This is generally attributed to a diminution of the volume of the reservoir and also of the stem, occasioned by the pressure of the atmosphere. It is usual with very delicate thermometers to fill them two or three years before they are graduated.

Besides this slow displacement, there are often variations in the position of the zero, when the thermometer has been exposed to high temperatures, caused by the fact that the bulb and stem do not contract on cooling to their original volume (271), and hence it is necessary to verify the position of zero when a thermometer is used for delicate determinations.

Regnault has found that some mercurial thermometers, which agree at 0° and at 100°, differ between these points, and that these differences frequently amount to several degrees. Regnault thinks that this is due to the unequal expansion of different kinds of glass.

280. **Limits to the employment of mercurial thermometers.**—Of all thermometers in which liquids are used, the one with mercury is the most useful, because this liquid expands most regularly, and is easily obtained pure, and because its expansion between $-36°$ and $100°$ is

regular, that is, proportional to the degree of heat. It also has the advantage of having a very low specific heat. But for temperatures below −36 C. the alcohol thermometer must be used, for mercury solidifies at −40° C. Above 100 degrees the coefficient of expansion increases and the indications of the mercurial thermometers are only approximate, the error arising sometimes to several degrees. Mercurial thermometers also cannot be used for temperatures above 350°, for this is the boiling point of mercury.

281. **Alcohol thermometer.**—The *alcohol thermometer* differs from the mercurial thermometer in being filled with coloured alcohol. But as the expansion of liquids is less regular in proportion as they are near the boiling point, alcohol, which boils at 78° C., expands very irregularly. Hence, alcohol thermometers are usually graduated by placing them in baths at different temperatures together with a standard mercurial thermometer, and marking on the alcohol thermometer the temperature indicated by the mercurial thermometer. In this manner the alcohol thermometer is comparable with the mercurial one; that is to say, it indicates the same temperatures under the same conditions. The alcohol thermometer is especially used for low temperatures, for it does not solidify at the greatest known cold.

282. **Conditions of the delicacy of a thermometer.**—A thermometer may be delicate in two ways:—1. When it indicates very small changes of temperature. 2. When it quickly assumes the temperature of the surrounding medium.

The first object is attained by having a very narrow capillary tube and a very large bulb; the expansion of the mercury on the stem is then limited to a small number of degrees, the 10 to 20 or 20 to 30 for instance, so that each degree occupies a great length on the stem, and can be subdivided into very small fractions. The second kind of delicacy is obtained by making the bulb very small, for then it rapidly assumes the temperature of the liquid in which it is placed.

A good mercurial thermometer should answer to the following tests: When its bulb and stem, to the top of the column of mercury, are immersed in melting ice, the top of the mercury should exactly indicate 0° C.; and when suspended with its bulb and scale immersed in the steam of water boiling in a metal vessel (as in fig. 233), the barometer standing at 760 mm., the mercury should be stationary at 100° C. When the instrument is inverted, the mercury should fill the tube, and fall with a metallic click, thus showing the complete exclusion of air. The value of the degrees should be uniform: to ascertain this, a little cylinder of mercury may be detached from the column by a slight jerk, and on inclining the tube it may be made to pass from one portion of the bore to another. If the scale be properly graduated, the column will occupy an equal number of degrees in all parts of the tube.

283. **Leslie's differential thermometer.**—Sir John Leslie constructed a thermometer for showing the difference of temperature of two neighbouring places, from which it has received the name *differential thermometer*. It consists of two glass bulbs containing air, and joined by a

bent glass tube of small diameter fixed on a frame (fig. 236). Before the apparatus is sealed, a coloured liquid is introduced in sufficient quantity to fill the horizontal part of the tube, and about half the vertical legs. It is important to use a liquid which does not give off vapours at ordinary temperatures, and dilute sulphuric acid coloured with litmus is generally preferred. The apparatus being closed, the air is passed from one bulb into the other by heating them unequally until the level of the liquid is the same in both branches. A zero is marked at each end of the liquid column. To graduate the apparatus, one of the bulbs is raised to a temperature 10° higher than the other. The air of the first is expanded and causes the column of liquid *ba* to rise in the other leg. When the column is stationary, the number 10 is marked on each side at the level of the liquid, the distance between zero and 10 being divided into 10 equal parts, both above and below zero, on each leg.

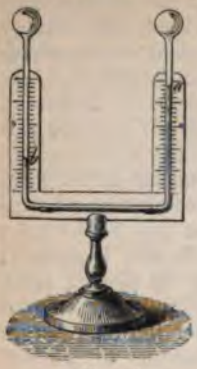


Fig. 236.

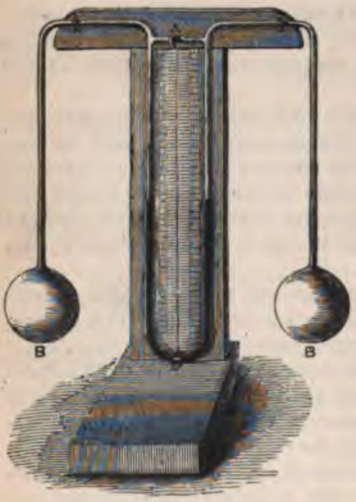


Fig. 237.

284. **Matthiessen's differential thermometer.** — Professor Matthiessen devised a form of differential thermometer which can be used for indicating the temperature of liquids, and which constitutes a valuable addition to our means of illustrating for lecture purposes many important experiments in heat. Its construction is evident from the annexed figure (237). The bulbs are pendent, and it can therefore be readily immersed in a liquid. In a tube which connects the two limbs there is a stopcock, which is very useful as a means of adjusting the level of the liquids, a rather troublesome task with Leslie's instrument,

285. **Breguet's metallic thermometer.**—Breguet invented a thermometer founded on the unequal expansion of metals, and remarkable for its delicacy. It consists of three strips of platinum, gold, and silver, which are passed through a rolling mill so as to form a very thin metallic ribbon. This is then coiled in a spiral form, as seen in fig. 238, and one end being fixed to a support, a light needle is fixed to the other, which is free to move round a graduated scale.

Silver, which is the most expansible of the metals, forms the internal

e of the spiral, and platinum the external. When the temperature
es, the silver expands more than gold or platinum, the spiral un-
nds itself, and the needle moves from left to right of the above figure.
e contrary effect is produced when
temperature sinks. The gold is
aced between the other two metals,
cause its expansibility is interme-
ate between that of the silver and
platinum. Were these two metals
ployed alone, their rapid unequal
pansion might cause a fracture.
eguet's thermometer is graduated in
ntigrade degrees, by comparing it
th a standard mercurial thermo-
eter.

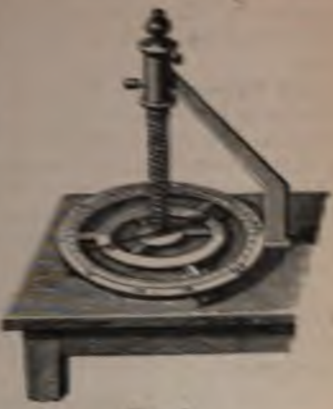


Fig. 238.

86. **Rutherford's maximum and
nimum thermometers.**—It is ne-
ssary, in meteorological observations,
know the highest temperature of
day and the lowest temperature
the night. Ordinary thermometers
uld only give these indications by a continuous observation, which
uld be impracticable. Several instruments have accordingly been in-
nted for this purpose, the simplest of which is Rutherford's. On a
tangular piece of plate glass (fig. 239) two thermometers are fixed,

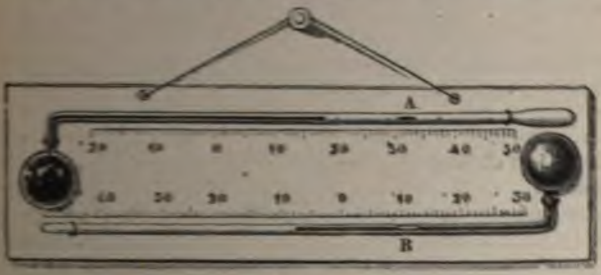


Fig. 239.

ose stems are bent horizontally. The one, A, is a mercurial, and the
her, B, an alcohol thermometer. In A there is a small piece of iron
re, A, moving freely in the tube, which serves as an index. The ther-
meter being placed horizontally, when the temperature rises the mer-
y pushes the index before it. But as soon as the mercury contracts
index remains in that part of the tube to which it has been moved,
there is no adhesion between the iron and the mercury. In this way
index registers the highest temperature which has been attained ; in
figure this is 31°. In the minimum thermometer there is a small
low glass tube which serves as index. When it is at the end of the

column of liquid, and the temperature falls, the column contracts, carries the index with it, in consequence of adhesion, until it has reac the greatest contraction. When the temperature rises, the alcohol pands, and passing between the sides of the tube and the index, does displace B. The position of the index gives therefore the lowest temp ature which has been reached: in the figure this was 9½ degrees b zero.

287. **Pyrometers.**—The name *pyrometers* is given to instruments measuring temperatures so high that mercurial thermometers could be used. The older contrivances for this purpose, Wedgewood's, Dani (which in principle resembled the apparatus in fig. 227), Brongniart's, are gone entirely out of use. None of them gives an exact measure temperature. The arrangements now used for the purpose are based on the expansion of gases and vapours, or on the electrical prop ties of bodies, and will be subsequently described.

288. **Different remarkable temperatures.**—The following table gi some of the most remarkable points of temperature. It may be observ that it is easier to produce very elevated temperatures than very low grees of cold.

Greatest artificial cold produced by a bath of bisulphide of carbon and liquid nitrous acid	– 140° C.
Greatest cold produced by ether and liquid carbonic acid	– 110
Greatest natural cold recorded in Arctic expeditions	– 49
Mercury freezes	– 39·4
Mixture of snow and salt	– 20
Ice melts	0
Greatest density of water	+ 4
Mean temperature of London	9·9
Blood heat	36·6
Water boils	100
Mercury boils	350
Red heat (just visible) (Daniell)	526
Silver melts ,,	1000
Cast iron melts ,,	1530
Highest heat of wind furnace ,,	1800

CHAPTER II.

EXPANSION OF SOLIDS.

289. **Linear expansion and cubical expansion. Coefficients expansion.**—It has been already explained that in solid bodies the pansion may be according to three dimensions—linear, superficial, cubical.

The *coefficient of linear expansion* is the elongation of the unit of len a body when its temperature rises from zero to one degree; the *coeffi- t of superficial expansion* is the increase of the surface in being heated n zero to 1 degree, and the *coefficient of cubical expansion* is the in- se of the unit of volume under the same circumstances.

hese coefficients vary with different bodies, but for the same body *the ficient of cubical expansion is three times that of the linear expansion,* s seen from the following considerations. Suppose a cube, the length hose side is 1 at zero. Let k be the elongation of this side in passing n zero to 1 degree, its length at 1 degree will be $1+k$, and the volume ne cube, which was 1 at zero, will be $(1+k)^3$, or $1+3k+3k^2+k^3$. But he elongation k is always a very small fraction (see table, art. 285), its are k^2, and its cube k^3, are so small that they may be neglected, and value at 1 degree becomes very nearly $1+3k$. Consequently, the in- se of volume is $3k$, or thrice the coefficient of linear expansion.

n the same manner it may be shown that the coefficient of superficial ansion is double the coefficient of linear expansion.

90. **Measurement of the coefficient of linear expansion. Lavoisier Laplace's method.**—The apparatus used by Lavoisier and Laplace determining the coefficients of linear expansion (fig. 240) consists of a

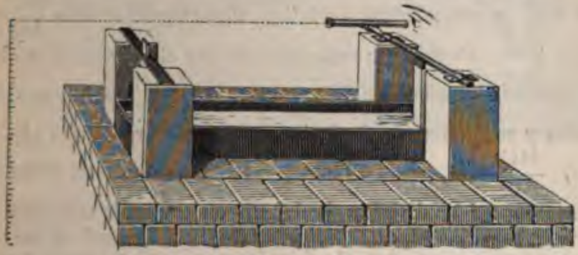


Fig. 240.

s trough, placed on a furnace between four stone supports. On the supports, on the right hand, there is a horizontal axis, at the end of h is a telescope; on the middle of this axis, and at right angles to it, ed a glass rod, turning with it, as does also the telescope. The other upports are joined by a cross piece of iron, to which another glass s fixed, also at right angles. The trough, which contains oil or water,

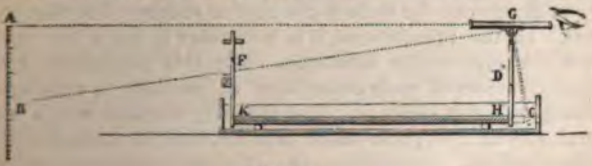


Fig. 241.

ted by a furnace not represented in the figure, and the bar whose sion is to be determined is placed in it.

241 represents a section of the apparatus; G is the telescope, KH

the bar, whose ends press against the two glass rods F and D. As the rod F is fixed, the bar can only expand in the direction KH, and in order to eliminate the effects of friction it rests on two glass rollers. Lastly, the telescope has a cross-view in the eyepiece, which, when the telescope moves, indicates the depression by the corresponding number of divisions on a vertical scale, AB, at a distance of 220 yards.

The trough is first filled with ice, and the bar being at zero, the division on the scale AB, corresponding to the wire of the telescope, is read off. The ice having been removed, the trough is filled with oil or water, which is heated to a given temperature. The bar then expands, and when its temperature has become stationary, which is determined by means of thermometers, the division of the scale, seen through the telescope, is read off.

From these data the elongation of the bar is determined; for since it has become longer by a quantity, CH, and the optical axis of the telescope has become inclined in the direction GB, the two triangles, GHC and ABG, are similar, for they have the sides at right angles each to each, so that $\frac{HC}{AB}=\frac{GH}{AG}$. In the same way, if HC′ were another elongation, and AB′ a corresponding deviation, there would still be $\frac{HC'}{AB'}=\frac{GH}{AG}$; from which it follows that the ratio between the elongation of the bar and the deflection of the telescope is constant, for it is always equal to $\frac{GH}{AG}$. A preliminary measurement had shown that this ratio was $\frac{1}{744}$. Consequently, $\frac{HC}{AB}=\frac{1}{744}$, whence $HC=\frac{AB}{744}$; that is, the total elongation of the bar is obtained by dividing the length on the scale traversed by the cross wire by 744. Dividing this elongation by the length of the bar, and then by the temperature of the bath, the quotient is the dilatation for the unit of length and for a single degree—in other words, the coefficient of linear dilatation.

291. **Roy and Ramsden's method.**—Lavoisier and Laplace's method is founded on an artifice which is frequently adopted in physical determinations, and which consists in amplifying by a known amount dimensions which, in themselves, are too small to be easily measured. Unfortunately this plan is often more fallacious than profitable, for it is first necessary to determine the ratio of the motion measured to that on which it depends. In the present case it is necessary to know the lengths of the arms of the level in the apparatus. But this preliminary operation may introduce errors of such importance as partially to counterbalance the advantage of great delicacy. The following method, which was used by General Roy in 1787, and which was devised by Ramsden, depends on another principle. It measures the elongations directly, and without amplifying them, but it measures them by means of a micrometer, which indicates very small displacements.

The apparatus (fig. 242) consists of three parallel metal troughs about 6 feet long. In the middle one there is a bar of the body whose expan-on is to be determined, and in the two others are cast-iron bars of actly the same length as this bar. Rods are fixed vertically on both des of these three bars. On the rods in the troughs A and B there are ngs with cross-wires like those of a telescope. On the rods in the trough C are small telescopes also provided with cross-wires.

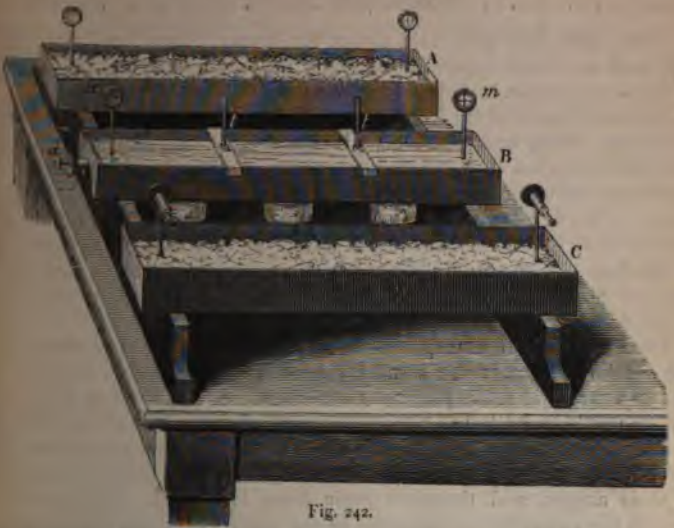


Fig. 242.

The trough being filled with ice, and all three bars at zero, the points of intersection of the wires in the disc, and of the wires in the telescope, are all in a line at each end of the bar. The temperature in the middle trough is then raised to 100° C. by means of spirit lamps placed beneath the trough; the bar expands, but as it is in contact with the end of a screw, *a*, fixed on the side, all the elongation takes place in the direction ne, and as the cross-wire *n* remains in position, the cross-wire *m* is moved towards B by a quantity equal to the elongation. But since the screw *p* is attached to the bar, by turning it slowly from right to left, the bar is moved in the direction *mn*, and the cross-wire *m* regains its original position. To effect this, the screw has been turned by a quantity exactly equal to the elongation of the bar, and as this advance of the screw is readily deduced from the number of turns of its *thread* (11), the total expansion of the bar is obtained, which, divided by the temperature of the bath, and this quotient by the length of the bar at zero, gives the coefficient of linear expansion.

Coefficients of linear expansion for 1° *between* 0° *and* 100° *C.*

White glass . . .	0·000008613	Cast iron	0·000011250
Platinum	0·000008842	Wrought iron . . .	0·000012204
Untempered steel .	0·000010788	Tempered steel . .	0·000012395

Coefficients of linear expansion—continued.

Gold	0·000014660	Silver	0·00001909
Copper	0·000017182	Tin	0·00002173
Bronze	0·000018167	Lead	0·00002857
Brass	0·000018782	Zinc	0·00002941

From what has been said about the linear dilatation (289), the coefficients of cubical expansion of solids are obtained by multiplying thos of linear expansion by three.

The coefficients of the expansion of the metals vary with their physical condition, being different for the same metal according as it has been cast or hammered and rolled, hardened or annealed. As a general rule, operations which increase the density increase also the rate of expansion. But even for substances in apparently the same condition, different observers have found very unequal amounts of expansions; this may arise in the case of compound substances, such as glass, brass, or steel, from a want of uniformity in chemical composition, and in simple bodies from slight differences of physical state.

The expansion of amorphous solids, and of those which crystallise in the regular system, is the same for all dimensions, unless they are subject to a strain in some particular direction. A fragment of such a substance varies in bulk, but retains the same shape. Crystals not belonging to the regular system exhibit when heated an unequal expansion in the direction of their different axes, in consequence of which the magnitude of their angles, and therefore their form, is altered. In the dimetric system the expansion is the same in the direction of the two equal axes, but different in the third. In crystals belonging to the hexagonal system the expansion is the same in the direction of the three secondary axes; but different from that according to the principal one. In the trimetric system it is different in all three directions.

292. **The coefficients of expansion increase with the temperature.**—According to Dr. Matthiessen, who determined the expansion of the metals and alloys by weighing them in water at different temperatures, the coefficients of expansion are not quite regular between 0° and 100°. He found the following values for the linear expansion between 0° and 100° :—

Zinc . . . $L_t = L_0 (1 + 0{\cdot}00002741\, t + 0{\cdot}0000000235\, t^2)$
Lead . . $L_t = L_0 (1 + 0{\cdot}00002726\, t + 0{\cdot}0000000074\, t^2)$
Silver . . $L_t = L_0 (1 + 0{\cdot}00001809\, t + 0{\cdot}0000000135\, t^2)$
Copper . . $L_t = L_0 (1 + 0{\cdot}00001408\, t + 0{\cdot}0000000264\, t^2)$
Gold . . $L_t = L_0 (1 + 0{\cdot}00001358\, t + 0{\cdot}0000000112\, t^2)$

The same authority has found that alloys expand very nearly according to the following law :—'the coefficients of expansion of an alloy are equa to the mean of the coefficients of expansion of the volumes of the metal composing it.'

293. **Formulæ relative to the expansion of solids.**—Let l be th length of a bar at zero, l' its length at the temperature t° C., and

coefficient of linear expansion. The tables usually give the expansion for 1° between 0° and 100°, as in article 285, or for 100°; in this latter case α is obtained by dividing the number by 100.

The relation existing between the above quantities is expressed by a few simple formulæ.

The elongation corresponding to $t°$ is t times α or αt for a single unit of length, or αtl for l units. The length of the bar which is l at zero is $l+\alpha tl$ at $t°$, consequently,

$$l' = l + \alpha tl = l(1 + \alpha t)$$

This formula gives the length of a body l' at $t°$, knowing its length l at zero, and the coefficient of expansion α; and by simple algebraical transformations, we can obtain from it formulæ for the length at zero, knowing the length l' at $t°$, and also for finding α the coefficient of linear expansion, knowing the lengths l' and l at $t°$ and zero respectively.

It is obvious that the formulæ for cubical expansion are entirely analogous to the preceding.

The following are examples of the application of these formulæ :—

A metal bar has a length l' and $t'°$, what will be its length l at $t°$?

From the above formula we first get the length of the given bar at zero, which is $\frac{l'}{1+\alpha t}$; by means of the same formula we pass from zero to $t°$ in multiplying by $1+\alpha t'$, which gives for the desired length the formula

$$l = \frac{l'(1 + \alpha t')}{1 + \alpha t}$$

The density of a body being d at zero, required its density d' at $t°$.

If 1 be the volume of the body at zero, and D its coefficient of cubical expansion, the volume at t will be $1 + Dt$, and as the density of a body is in inverse ratio of the volume which the body assumes in expanding, we get the inverse proportion,

$$d' : d = 1 \ : \ 1 + Dt,$$

$$\frac{d'}{d} = \frac{1}{1 + Dt}; \text{ or } d' = \frac{d}{1 + Dt}$$

Consequently, when a body is heated from 0 to $t°$, its density, and therefore its weight for an equal volume, is inversely as the binomial expression, $1 + Dt$.

294. **Applications of the expansion of solids.**—In the arts we meet with numerous examples of the influence of expansion. (i.) The bars of furnaces must not be fitted tightly at their extremities, but must, at least, be free at one end, otherwise, in expanding, they would split the masonry. (ii.) In making railways a small space is left between the successive rails, for if they touched, the force of expansion would cause them to curve or would break the chairs. (iii.) Water pipes are fitted to one another by means of telescopic joints, which allow room for expansion. (iv.) If a glass is heated or cooled too rapidly it cracks; this arises from the fact that glass, being a bad conductor of heat, the sides become unequally heated, and consequently unequally expanded, which causes a fracture.

When bodies have been heated to a high temperature, the for duced by their contraction on cooling is very considerable; it is e the force which is needed to compress or expand the material same extent by mechanical means. According to Barlow a bar c leable iron a square inch in section is stretched $\frac{1}{10000}$th of its len a weight of a ton; the same increase is experienced by about 9° difference of 45° C. between the cold of winter and the heat of s is not unfrequently experienced in this country. In that range a wr iron bar ten inches long will vary in length by $\frac{1}{200}$th of an inch and wi a strain, if its ends are securely fastened, of fifty tons. It has be culated from Joule's data that the force exerted by heat in expan pound of iron between 0° and 100° during which it increases abou of its bulk, is equal to 16,000 foot pounds; that is, it could raise a of 7 tons through a height of one foot.

(i.) An application of this contractile force is seen in the m securing the tires on wheels. The tire being made red hot, an considerably expanded, is placed circumference of the wheel and cooled. The tire, when cold, em the wheel with such force as not secure itself on the rim, but also t home the joints of the spokes in felloes and nave. (ii.) Another in ing application was made in the a gallery at the Conservatoire de et Métiers in Paris, the walls of had begun to bulge outwards. Iro were passed across the buildin screwed into plates on the outside walls. Each alternate bar wa heated by means of lamps, and wh bar had expanded it was screw The bars being then allowed to co tracted, and in so doing drew th together. The same operation w formed on the other bars.

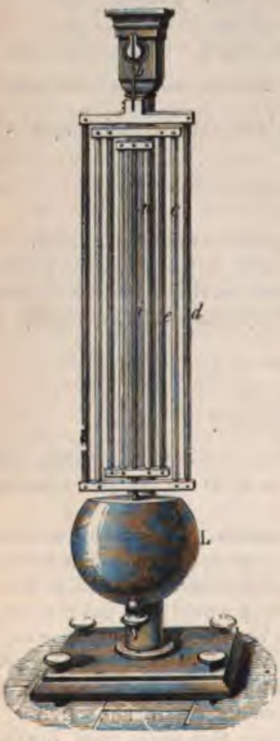


Fig. 243.

295. **Compensation pendulum** important application of the exp of metals has been made in *the c sation pendulum.* This is a pendu which the elongation, when the te ture rises, is so compensated th distance between the centre of susp and the centre of oscillation (74) r constant, which, from the laws pendulum (75), is necessary for i nous oscillations, and in order th pendulum may be used as a regulator of clocks.

fig. 243, which represents the *gridiron* pendulum, one of the com-
t forms of compensation pendulums, the ball, L, instead of being
rted by a single rod, is supported by a framework, consisting of
te rods of steel and brass. In the figure the shaded rods represent
including a small steel rod, *b*, which supports the whole of the
tus, there are six of them. The rest of the rods, four in number,
brass. The rod *i*, which supports the ball, is fixed at its upper
a horizontal cross-piece; at its lower end it is free, and passes
h the two circular holes in the lower horizontal cross-pieces.

it is easy to see from the manner in which the vertical rods are
o the cross-pieces, that the elongation of the steel rods can only
lace in a downward direction, and that of the brass rods in an
d direction. Consequently, in order that the pendulum may remain
same length, it is necessary that the elongation of the brass rods
end to make the ball rise by exactly the same quantity that the
tion of the steel rod tends to lower it : a result which is attained
the sum of the lengths of the steel rods A is to the sum of the
s of the brass rods B in the inverse ratio of the coefficients of ex-
n of steel and brass, *a* and *b*, that is, in the proportion $A : B = b : a$.

elongation of the rod may also be compensated for by means of
sating strips. These consist of two blades of copper and iron
d together and fixed to the pendulum rod, as represented in
. The copper blade, which is more expansible, is below the iron.
the temperature sinks, the pendulum rod becomes shorter, and the
es. But at the same time the compensating strips become curved,
in fig. 245, in consequence of the copper contracting more than

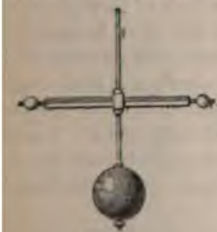


Fig. 244.

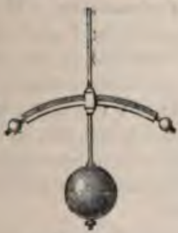


Fig. 245.

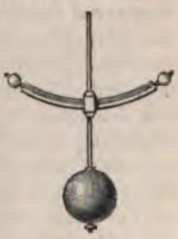


Fig. 246.

n, and two metallic balls at their extremities become lower. If they
he proper size in reference to the pendulum ball, the parts which
approach the centre of suspension compensate those which tend
ove from it, and the centre of oscillation is not displaced. If the
rature rises the pendulum ball descends, but at the same time the
balls ascend, as shown in fig. 246, so that there is always com-
ion.

of the most simple compensating pendulums is the *mercury pen-*
, invented by an English watchmaker, Graham. The ball of the
lum, instead of being solid, consists of a glass cylinder, containing
mercury, which is placed in a sort of stirrup, supported by a steel

rod. When the temperature rises the rod and stirrup become longer, and thus lower the centre of gravity ; but at the same time the mercury expands, and, rising in the cylinder, produces an inverse effect, and as mercury is much more expansible than steel, a compensation may be effected without making the mercurial vessel of undue dimensions.

The same principle is applied in the *compensating balances* of chronometers. The motion here is regulated by a *balance* or wheel, furnished with a spiral spring, and the time of the chronometer depends on the force of the spring, the mass of the balance, and on its circumference. Now when the temperature rises the circumference increases, and the chronometer goes slower ; and to prevent this, part of the mass must be brought nearer the axis. On the circumference of the balance compensating strips are fixed, of which the more expansible metal is on the outside, and at the end of these are small masses of metal which play the same part as the balls in the above case. When the radius is expanded by heat, the small masses are brought nearer the centre in consequence of the curvature of the strips ; and as they can be fixed in any position, they are easily arranged so as to compensate for the expansion of the balance.

CHAPTER III.

EXPANSION OF LIQUIDS.

296. **Apparent and real expansion.**—If a flask of thin glass, provided with a capillary stem, the flask and part of the stem being filled with some coloured liquid, be immersed in hot water, the column of liquid in the stem at first sinks, but then immediately after rises, and continues to do so until the liquid inside has the same temperature as the hot water. This first sinking of the liquid is not due to its contraction; it arises from the expansion of the glass, which becomes heated before the heat can reach the liquid ; but the expansion of the liquid soon exceeds that of the glass, and the liquid ascends.

Hence in the case of liquids we must distinguish between the *apparent* and the *real* or *absolute* expansion. The apparent expansion is that which is actually observed when liquids contained in vessels are heated: the *absolute* expansion is that which would be observed if the vessel did not expand; or, as this is never the case, it is the apparent expansion corrected for the simultaneous expansion of the containing vessel.

As has been already stated, the cubical expansion of liquids is alone considered ; and as in the case of solids, the *coefficient of expansion* of a liquid is the increase of the unit of volume for a single degree, but a distinction is here made between the *coefficient of absolute expansion* and the *coefficient of apparent expansion*. Of the many methods which have been employed for determining these two coefficients, we shall describe that of Dulong and Petit.

97. **Coefficient of the absolute expansion of mercury.**—In order to ermine the coefficient of absolute expansion of mercury, the influence of envelope must be eliminated. Dulong and Petit's method depends on hydrostatical principle that, in two communicating vessels, the heights wo columns of liquid in equilibrium are inversely as their densities), a principle independent of the diameters of the vessels, and therefore heir expansions.

he apparatus consists of two glass tubes, A and B (fig. 247), joined by apillary tube, and kept vertical on an iron support, KM, the horizonty of which is adjusted by means of two levelling screws and two spirit els, *m* and *n*. Each of the tubes is surrounded by a metal case, of ich the smaller, D, is filled with ice; the other, E, containing oil, can heated by the furnace, which is represented in section so as to show case. Mercury is poured into the tubes A and B; it remains at the e level in both as long as they are at the same temperature, but rises B in proportion as it is heated, and expands.

et h and d be the height and density of the mercury in the leg A, at temperature zero, and h' and d' the same quantities in the leg B. From hydrostatical principle previously cited we have had $hd = h'd'$. Now n the problem in article 293, $d' = \frac{d}{1 + Dt}$, D being the coefficient of abte expansion of mercury; substituting this value of d' in the equation, have $\frac{h'd}{1 + Dt} = hd$, from which we get $D = \frac{h' - h}{ht}$.

he coefficient of absolute expansion of mercury is obtained from this

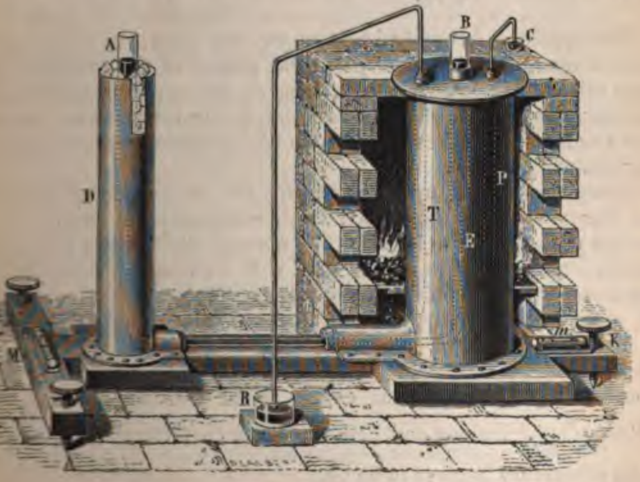


Fig. 247

nula, knowing the heights h' and h, and the temperature t of the bath which the tube B is immersed. In Dulong and Petit's experiment this temperature was measured by a weight thermometer, P (299), t mercury of which overflowed into the basin, C, and by means of an thermometer, T (308) ; the heights h' and h were measured by a cathet meter, K (83).

Dulong and Petit found by this method that the coefficient of absolu expansion of mercury, between 0° and 100° C. is $\frac{1}{5550}$. But they fou that the coefficient increased with the temperature. Between 100° a 200° it is $\frac{1}{5425}$, and between 200° and 300° it is $\frac{1}{5300}$. The same observ tion has been made in reference to other liquids, showing that their e pansion is not regular. It has been found that this expansion is le regular in proportion as liquids are near a change in their state of aggr gation, that is, approach their freezing or boiling points. Dulong a Petit found that the expansion of mercury between −36° and 100° is pra tically quite uniform.

Regnault, who has determined this important physical constant, h found that the mean coefficient between 0° and 100° is $\frac{1}{5508}$, between 10 and 200°, $\frac{1}{5374}$, and between 200° and 300°, $\frac{1}{5218}$.

298. **Coefficient of the apparent expansion of mercury.**—The c efficient of apparent expansi of a liquid varies with the n ture of the envelope. That mercury in glass was dete mined by means of the app ratus represented in figure 24 It consists of a glass cylind to which is joined a bent cap lary glass tube, open at the en

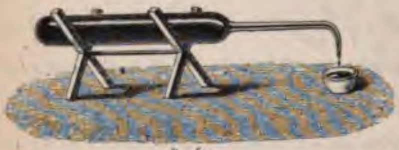


Fig. 248.

The apparatus is weighed first empty, and then when filled with me cury at zero; the difference gives the weight of the mercury, P. It then raised to a known temperature, t ; the mercury expands, a certa quantity passes out, which is received in the capsule and weighed. the weight of this mercury be p, that of the mercury remaining in the a paratus will be $P-p$.

When the temperature is again zero, the mercury in cooling produc an empty space in the vessel, which represents the contraction of t weight of mercury $P-p$, from $t°$ to zero, or, what is the same thing, t expansion of the same weight from 0 to $t°$, that is, the weight p repr sents the expansion of the weight $P-p$, for $t°$. If this weight expan in glass by a quantity p for $t°$, a single unit of weight would expa $\frac{p}{(P-p)}$ for $t°$ and $\frac{p}{(P-p)t}$ for a single degree; consequently, for I the coefficient of apparent expansion of mercury in glass, we ha $D'=\frac{p}{(P-p)t}$. Dulong and Petit found the coefficient of apparent expa sion of mercury in glass to be $\frac{1}{6480}$.

299. **Weight thermometer.**—The apparatus represented in fig. 248 called the *weight thermometer*, because the temperature can be deduc from the weight of mercury which overflows.

The above experiments have placed the coefficient of apparent expansion at $\frac{1}{6480}$; we have therefore the equation $\frac{p}{(\mathrm{P}-p)t}=\frac{1}{6480}$, from which we get $t=\frac{6480p}{\mathrm{P}-p}$, a formula which gives the temperature t when the weights P and p are known.

300. **Coefficient of the expansion of glass.**—As the absolute expansion of a liquid is the apparent expansion *plus* the expansion due to the envelope, the coefficient of the cubical expansion of glass has been obtained by taking the difference between the coefficient of absolute expansion of mercury in glass and that of its apparent expansion. That is, the coefficient of cubical expansion of glass is

$$\frac{1}{5508}-\frac{1}{6480}=\frac{1}{38700}=0{\cdot}002584.$$

Regnault has found that the coefficient of expansion varies with different kinds of glass, and further with the form of the envelopes. For ordinary chemical glass tubes, the coefficient is 0·0000254.

301. **Coefficients of expansion of various liquids.**—The apparent expansion of liquids may be determined by means of the weight thermometer, and the absolute expansion is obtained by adding to this coefficient the expansion of the glass.

Total apparent expansions of liquids between 0° and 100° C.

Mercury	0·01543	Oil of turpentine . . .	0·07
Distilled water . . .	0·0466	Ether	0·07
Water saturated with salt .	0·05	Fixed oils	0·08
Sulphuric acid . . .	0·06	Nitric acid	0·11
Hydrochloric acid . .	0·06	Alcohol	0·116

The coefficient of apparent expansion for 1° C. is obtained by dividing these numbers by 100; but the number thus obtained does not represent the mean coefficient of expansion of liquids, for the expansion of these bodies increases gradually from zero. The expansion of mercury is practically constant between −36° and 100° C., while water contracts from zero to 4°, and then expands.

For many physical experiments a knowledge of the exact expansion of water is of great importance. This physical constant has been determined with great care by Dr. Matthiessen, who has found that between 4° and 32° it may be expressed by the formula

$$\mathrm{V}t=1-0{\cdot}00000253\,(t-4)+0{\cdot}0000008389\,(t-4)^2+\\0{\cdot}00000007173\,(t-4)^3;$$

and between 30° and 100° by

$$\mathrm{V}t=0{\cdot}999695+0{\cdot}0000054724\,t^2+0{\cdot}00000001126\,t^3.$$

Many liquids, with low boiling points, especially condensed gases, have very high coefficients of expansion. Thilorier found that liquid carbonic acid expands four times as much as air. Drion has recently confirmed this observation, and has obtained analogous results with chloride of ethyle, liquid sulphurous acid, and liquid hyponitrous acid.

302. **Correction of the barometric height.**—It has been already explained under the Barometer (159), that, in order to make the indications of this instrument comparable in different places and at different times, they must be reduced to a uniform temperature, which is that of melting ice. The correction is made in the following manner :—

Let H be the barometric height at $t°$, and h its height at zero, d the density of mercury at zero, and d' its density at $t°$. The heights H and h are inversely as the densities d and d'; that is, $\frac{h}{H}=\frac{d'}{d}$. If we call 1 the volume of mercury at zero, its volume at $t°$ will be $1+Dt$, D being the coefficient of absolute expansion of mercury. But these volumes, $1+Dt$ and 1, are inversely as the densities d and d'; that is, $\frac{d'}{d}=\frac{1}{1+Dt}$. Consequently, $\frac{h}{H}=\frac{1}{1+Dt}$, whence $h=\frac{H}{1+Dt}$. Replacing D by its value $\frac{1}{5508}$, we have

$$h=\frac{H}{1+\frac{t}{5508}}=\frac{5508H}{5508+t}.$$

In this calculation, the coefficient of absolute expansion of mercury is taken, and not that of apparent expansion; for the value H is the same as if the glass did not expand, the barometric height being independent of the diameter of the tube, and therefore of its expansion.

303. **Force exerted by liquids in expanding.**—The force which liquids exert in expanding is very great, and equal to that which would be required in order to bring the expanded liquid back to its original volume. Now we know what an enormous force is required to compress a liquid to even a very small extent. Thus between 0° and 10°, mercury expands by 0·0017905 of its volume at 0°; its compressibility is 0·00000295 of its volume for one atmosphere; hence a pressure of more than 600 atmospheres would be requisite to prevent mercury expanding when heated from 0° to 10°.

304. **Maximum density of water.**—Water presents the remarkable phenomenon that when its temperature sinks it contracts up to 4°; but from that point, although the cooling continues, it expands up to the freezing point, so that 4° represent the point of greatest contraction of water.

Many methods have been used to determine the maximum density of water. Hope made the following experiment. He took a deep vessel, perforated by two lateral apertures, in which he fixed thermometers, and having filled the vessel with water at 0°, he placed it in a room at a temperature of 15°. As the layers of liquid at the sides of the vessel became heated they sank to the bottom, and the lower thermometer marked 4°, while that of the upper one was still at zero. Hope then made the inverse experiment: having filled the vessel with water at 15°, he placed it in a room at zero. The lower thermometer having sunk to 4°, remained stationary for some time, while the upper one cooled down until it reached zero. Both these experiments prove that water is heavier at 4° than at 0°, for in both cases it sinks to the lower part of the vessel.

This last experiment may be adapted for lecture illustrations by using a cylinder containing water at 15° C., surrounded with a sheath containing bruised ice (fig. 249).

Hallström made a determination of the maximum density of water in the following manner. He took a glass bulb, loaded with sand, and weighed it in water of different temperatures. Allowing for the expansion of glass, he found that 4·1° was the temperature at which it lost most weight, and consequently this was the temperature of the maximum density of water.

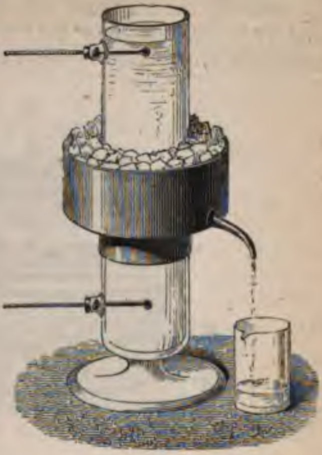


Fig. 249.

Despretz arrived at the temperature 4° by another method. He took a water thermometer, that is to say a bulbed tube containing water, and placing it in a bath, the temperature of which was indicated by an ordinary mercury thermometer, found that the water contracted to the greatest extent at 4°, and that this is therefore the point of greatest density.

This phenomenon is of great importance in the economy of nature. In winter the temperature of lakes and rivers falls from being in contact with the cold air, and from other causes, such as radiation. The colder water sinks to the bottom, and a continual series of currents goes on until the whole has a temperature of 4°. The cooling on the surface still continues, but the cooled layers being lighter remain on the surface, and ultimately freeze. The ice formed thus protects the water below, which remains at a temperature of 4°, even in the most severe winters, a temperature at which fishes and other inhabitants of the waters are not destroyed.

CHAPTER IV.

EXPANSION AND DENSITY OF GASES.

305. **Gay-Lussac's method.**—Gases are the most expansible of all bodies, and at the same time the most regular in their expansion. The coefficients of expansion, too, of the several gases differ only by very small quantities. The cubical expansion of gases need alone be considered.

Gay-Lussac first determined the coefficient of the expansion of gases by means of the apparatus represented in fig. 250.

In a rectangular metal bath, about 16 inches long, was fitted an air thermometer, which consisted of a capillary tube, AB, with a bulb at one end. The tube was divided into parts of equal capacity, and contents of the bulb ascertained in terms of these parts. This was effe by weighing the bulb and tube full of mercury at zero, and then hea slightly to expel a small quantity of mercury, which was weighed. apparatus being again cooled down to zero, the vacant space in the t

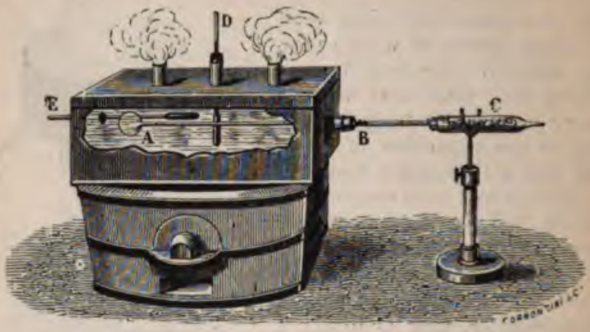


Fig. 250.

corresponded to the weight of mercury which had overflowed; volume of mercury remaining in the apparatus, and consequently volume of the bulb, was determined by calculations analogous to t made for the piezometer (92).

In order to fill the thermometer with dry air it was first filled mercury, which was boiled in the bulb itself. A tube, C, filled chloride of calcium, was then fixed on to its end by means of a cork. fine platinum wire having then been introduced into the stem AB, thr the tube C, and the apparatus being slightly inclined and agitated f time to time, air entered, having been previously well dried by pas through the chloride of calcium tube. The whole of the mercury displaced, with the exception of a small thread, which remained in tube AB as an index.

The air thermometer was then placed in the box filled with mel ice, the index moved towards A, and the point was noted at whi became stationary. This gave the volume of air at zero; for the cap of the bulb was known. Water or oil was then substituted for the and the bath successively heated to different temperatures. The ai panded and moved the index from A towards B. The position of index in each case was noted, and the corresponding temperature indicated by means of the thermometers D and E.

Assuming that the atmospheric pressure did not vary during experiment, and neglecting the expansion of the glass as being too s in comparison with that of the air, the total expansion of the a obtained by subtracting from its volume at a given temperature, its vo at zero. Dividing this by a given temperature, and then by the er of units contained in the volume at zero, the quotient is the coefficient f expansion for a single unit of volume and a single degree ; that is, the fficient of expansion. It will be seen, further on, how corrections for ressure and temperature may be introduced.

By this method Gay-Lussac found that the coefficient of expansion of ir was 0·00375 ; and he enunciated the two following laws in reference o the expansion of gases :—

I. *All gases have the same coefficient of expansion as air.*

II. *This coefficient is the same whatever be the pressure supported by the gas.*

These simple laws are not, however, rigorously exact (306) ; they only xpress the expansion of gases in an approximate manner.

306. **Problems on the expansion of gases.**—Many of the problems relative to the expansion of gases are similar to those on the xpansion of liquids. With obvious modifications, they are solved in a imilar manner. In most cases the pressure of the atmosphere must be taken into account in considering the expansion of gases. The following is an example of the manner in which this correction is made :—

i. The volume of a gas at $t°$, and under the pressure H, is V′ ; what will be the volume V of the same gas at zero, and under the normal pressure 760 millimeters?

Here there are two corrections to be made ; one relative to the temperature, and the other to the pressure. It is quite immaterial which s taken first. If a be the coefficient of cubical expansion for a single degree, by reasoning similar to that in the case of linear expansion (289), the volume of the gas at zero, but still under the pressure H, will be $\frac{V'}{1+at}$. This pressure is reduced to the pressure 760, in accordance with Boyle's law (166), by putting

$$V + 760 = \frac{V'}{1+at} \times H$$

whence

$$V = \frac{V'H}{760\,(1+at)}.$$

ii. A volume of gas weighs P′ at $t°$; what will be its weight at zero?

Let P be the desired weight, a the coefficient of expansion of the gas, d' its density at $t°$, and d its density at zero. As the weights of equal volumes are proportional to the densities, we have $\frac{P'}{P}=\frac{d'}{d}$. If 1 be the volume of a gas at zero, its volume at t will be $1+at$; but as the densities are inversely as the volumes $\frac{d'}{d}=\frac{1}{1+at}$, and therefore

$$\frac{P'}{P}=\frac{1}{1+at}$$

hence

$$P = P'(1+at).$$

From this equation we get $P' = \frac{P}{1 + \alpha t}$, which gives the weight a
knowing the weight at zero, and which further shows that the weight
is inversely as the binomial of expansion $1 + \alpha t$.

307. **Regnault's method.**—M. Regnault used successively four differe
methods for determining the expansion of gases. In some of them t
pressure was constant and the volume variable, as in Gay-Lussa
method; in others the volume remained the same while the pressu
varied. The first method will be described. It is the same as that u
by Rudberg and Dulong, but is distinguished by the care with which
sources of error are avoided.

The apparatus consisted of a pretty large cylindrical reservoir, B (
251), terminating in a bent capillary tube. In order to fill the reserv

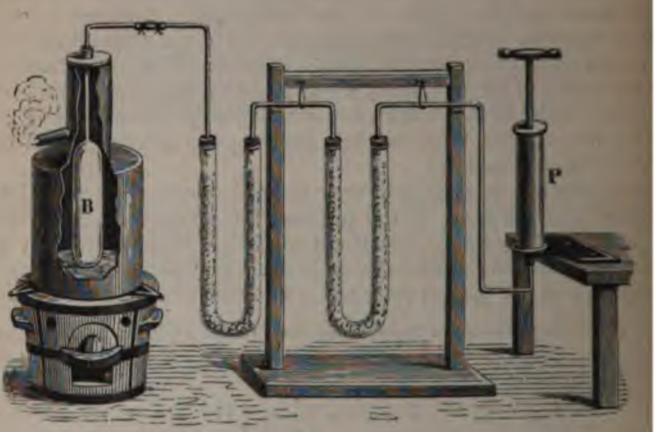


Fig. 251.

with dry air, it was placed in a hot water bath, and the capillary t
connected by a caoutchouc tube with a series of drying tubes. Th
tubes were joined to a small air pump, P, by which a vacuum could
produced in the reservoir while at a temperature of 100°. The reserv
was first exhausted, and air afterwards admitted slowly; this operat
was repeated a great many times, so that the air in the reservoir beca
quite dry, for the moisture adhering to the sides passed off in vapour
100°, and the air which entered became dry in its passage through the
tubes.

The reservoir was then kept for half an hour at the temperature
boiling water; the air pump having been detached, the drying tu
were then disconnected, and the end of the tube hermetically seal
the height, H, of the barometer being noted. When the reservoir B

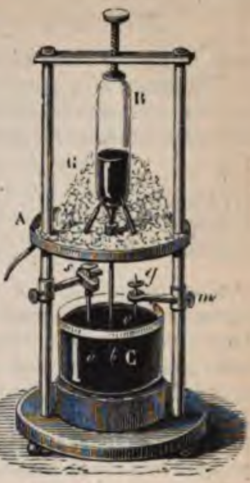


Fig. 252.

was placed in the apparatus represented in fig. 252. It was iite surrounded with ice, and the end ube dipped in the mercury bath, C. e air in the reservoir B had sunk to e point *b* was broken off by means ceps ; the air in the interior became ied by atmospheric pressure, the mer- ing to a height *o*G. In order to : the height of this column, G*o*, vill be called *h*, a movable rod, *go*, ered until its point, *o*, was flush : surface of the mercury in the bath ; ance between the point *o* and the the mercury G was measured by of the cathetometer. The point *b* ally closed with wax by means of the , and the barometric pressure noted noment. If this pressure be H, the : in the reservoir is H′ – *h*.

reservoir was now weighed to n P, the weight of the mercury it contained. It was then com- illed with mercury at zero, in order the weight P′ of the mercury in the reservoir ahd in the tube be the coefficient of the cubical expansion of glass, and D the of mercury at zero, the coefficient *α* of the cubical expansion ot termined in the following manner. The volume of the reservoir the tube at zero is $\frac{P'}{D}$, from the formula P = VD (120) ; conse- this volume is

$$\frac{P'}{D}(1 + \delta t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

emperature $t°$, assuming, as is the case, that the reservoir and and as if they were solid glass. But from the formula P = VD, me of air in the reservoir at zero, and under the pressure H′ – *h*. At the same pressure, but at $t°$, its volume would be

$$\frac{P' - P}{D}(1 + \alpha t)$$

Boyle's law (166), at the pressure H, under which the tube was his volume must have been

$$\frac{(P' - P)(1 + \alpha t)(H' - h)}{DH} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

he volumes represented by these formulas, (1) and (2), are each equal to the volume of the reservoir and the tube at $t°$; they are therefore equal. Removing the denominators, we have

$$P'(1+\delta t)H=(P'-P)(1+\alpha t)(H'-h) \quad \text{. . . . .} \quad (3)$$

from which the value of α is deduced.

The means of a great number of experiments between zero and 100°, and for pressures between 300 millimeters and 500 millimeters, gave the following numbers for the coefficients of expansion for a single degree :

Air	0·0036650	Hydrochloric acid . .	0·0036812
Hydrogen	0·0036678	Cyanogen	0·0036821
Nitrogen	0·0036682	Carbonic acid . . .	0·0036896
Sulphurous acid . . .	0·0036606		

These numbers, with which the results obtained by Magnus closely agree, show that the coefficients of expansion of the permanent gases differ very little; but that they are slightly greater in the case of the condensible gases, such as carbonic and sulphurous acids. Regnault has further found that, at the same temperature, the coefficient of expansion of any gas increases with the pressure which it supports. Finally, he has found that the coefficients of expansion of two different gases differ more in proportion as they are under greater pressures.

The number found by Regnault for the coefficient of the expansion of air, 0·003665, is equal to $\frac{1}{272{\cdot}9}=\frac{1}{273}$ nearly ; and if we take the coefficient of expansion at 0·0036666 . . . it may be represented by the fraction $\frac{11}{3000}$, which is very convenient for purposes of calculation.

308. **Air thermometer.**—The *air thermometer* is based on the expansion of air. When it is used to measure small differences of temperature, it has the same form as the tube used by Gay-Lussac in determining the expansion of air (fig. 250), that is, a capillary tube with a bulb at the end. The reservoir being filled with dry air, an index of coloured sulphuric acid is passed into the tube ; the apparatus is then graduated in Centigrade degrees by comparing the positions of the index with the indications of a mercurial thermometer. Of course the end of the tube must remain open ; otherwise, the air above the index condensing or expanding at the same time as that in the bulb, the index would remain stationary. A correction must be made at each observation for the atmospheric pressure.

When considerable variations of temperature are to be measured, the tube has a form like that used in Regnault's experiments (fig. 251 and 252). By experiments made as described in article 307, P, P′, H, H′, and h, may be found, and the coefficients α and δ being known, the temperature t to which the tube has been raised is readily deduced from the equation (3).

Regnault's researches show that the air and the mercurial thermometer agree up to 260°, but above that point mercury expands relatively more than air.

In cases where very high temperatures are to be measured the reservoir is made of platinum. The use of an air thermometer is seen in

Dulong and Petit's experiment (297); it was by such an apparatus that Pouillet measured the temperature corresponding to the colours which metals take when heated in a fire, and found them to be as follows :—

Incipient red	525°C.	Dark orange	1100°C.
Dull red	700	White	1300
Cherry red	900	Dazzling white	1500

In the measurement of high temperatures Deville and Troost have used, with advantage, the vapour of iodine instead of air.

309. **Density of gases.**—The relative *density* of a gas, or its *specific gravity*, is the ratio of the weight of a certain volume of the gas to that of the same volume of air; both the gas and the air being at zero and at a pressure of 760 millimeters.

In order, therefore, to find the specific gravity of a gas, it is necessary to determine the weight of a certain volume of this gas, at a pressure of 760 millimeters, and a temperature of zero, and then the weight of the same volume of air under the same conditions. For this purpose a large globe of about two gallons capacity is used, the neck of which is provided with a stopcock, which can be screwed to the air pump. The globe is first weighed empty, and then full of air, and afterwards full of the gas in question. The weights of the gas and of the air are obtained by subtracting the weight of the exhausted globe from the weight of the globes filled, respectively, with air and gas. The quotient, obtained by dividing the latter by the former, gives the specific gravity of the gas. It is difficult to make these determinations at the same temperature and pressure, and therefore all the weights are reduced to zero and the normal pressure of 760 millimeters.

The gases are dried by causing them to pass through drying tubes before they enter the globe, and air must also be passed over potash to free it from carbonic acid. And as even the best air pumps never produce a perfect vacuum, it is necessary to exhaust the globe until the manometer in each case marks the same pressure.

The globe having been exhausted, dried air is allowed to enter, and the process is repeated several times until the globe is perfectly dried. It is then finally exhausted until the residual tension, in millimeters, is e. The weight of the exhausted globe is p. Air, which has been dried and purified by passing through potash and chloride of calcium tubes, is then allowed to enter slowly. The weight of the globe full of air is P. If H is the barometric height in millimeters, and $t°$ the temperature at the time of weighing, $P-p$ is the weight of the globe full of air at the temperature t, and the pressure $H-e$.

To reduce this weight to the pressure 760 millimeters and the temperature zero, let a be the coefficient of the expansion of air, and δ the coefficient of the cubical expansion of glass. From Boyle's law the weight, which is $P-p$ at $t°$, and a pressure of $H-e$ would be $\frac{(P-p)\ 760}{H-e}$ under the pressure 760 millimeters and at the same temperature $t°$. If the temperature is 0°, the capacity of the globe will diminish in the ratio $1+\delta t$

to 1, while the weight of the gas increases in the ratio $1 : 1 + \alpha t$, as follows from the problems in art. 306. Consequently, the weight of the air in the globe at 0° and at the pressure 760 millimeters will be

$$(P - p)\frac{760\,(1 + \alpha t)}{(H - e)\,(1 + \delta t)} \quad \ldots \ldots \ldots \quad (1)$$

Further, let α' be the coefficient of expansion of the gas in question ; let P′ be the weight of the globe full of gas at the temperature t' and the pressure H′, and let p' be the weight of the globe when it is exhausted to the tension e ; the weight of the gas in the globe at the pressure 760 and the temperature zero will be

$$(P' - p')\frac{760\,(1 + \alpha' t')}{(H' - e)\,(1 + \delta t')} \quad \ldots \ldots \ldots \quad (2)$$

Dividing the latter formula by the former we obtain the density

$$D = \frac{(P' - p')\,(H - e)\,(1 + \alpha' t')\,(1 + \delta t)}{(P - p)\,(H' - e)\,(1 + \alpha t)\,(1 + \delta t')}$$

If the temperature and the pressure do not vary during the experiment, $H = H'$ and $t = t'$; whence $D = \frac{(P' - p')\,(1 + \alpha' t)}{(P - p)\,(1 + \alpha t)}$, and if $\alpha = \alpha'$, $D = \frac{P' - p'}{P - p}$.

310. **Regnault's method of determining the density of gases.**—M. Regnault has so modified the above method that many of the corrections may be dispensed with. The globe in which the gas is weighed is suspended from one pan of a balance, and is counterpoised by means of a second globe of the same dimensions, and hermetically sealed, suspended from the other. These two globes expanding at the same time always displace the same quantity of air, and consequently variations in the temperature and pressure of the atmosphere do not influence the weighing. The globe, too, is filled with the air or with the gas, at the temperature of zero. This is effected by placing it in a vessel full of ice, as shown in fig. 253. It is then connected with a three-way cock, A, by which it may be connected either with an air pump, or with the tubes M and N, which are connected with the reservoir of gas. The tube M and N contain substances by which their action on the gas dry and purify it.

The stopcock A being so turned that the globe is only connected with the air pump, a vacuum is produced ; by means of the same cock, the connection with the machine being cut off, but established between M and N, the gas soon fills the globe. But as the exhaustion could not have been complete, and some air must have been left, the globe is again exhausted and the [air] allowed to enter, and the process repeated until it is thought all air is removed. The globe being once more produced, a differential barometer (fig. 113), connected with the apparatus by th tube E, indicates the pressure of the residual rarefied gas e. Closing th cock B and detaching A, the globe is removed from the ice, and aft being cleaned is weighed.

gas

This gives the weight of the empty globe p'; it is again replaced in f ice, the stopcock A adjusted, and the gas allowed to enter, care being ken to leave the stopcocks open long enough to allow the gas in the be to acquire the pressure of the atmosphere, which is marked by the

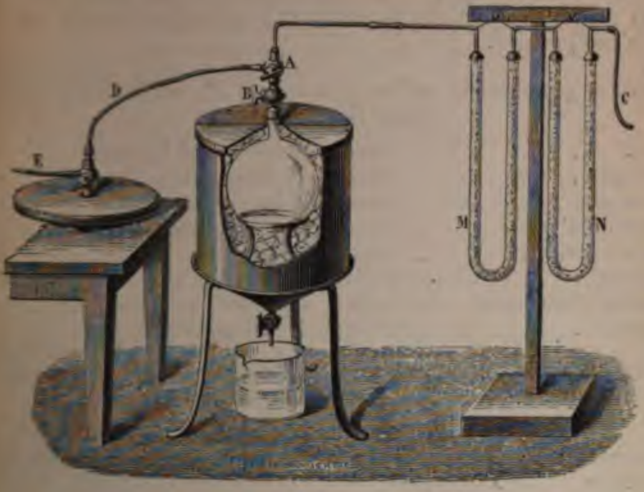


Fig. 253.

rometer H. The stopcock B is then closed, A removed, and the globe eighed with the same precautions as before. This gives the weight P_1 f the gas.

The same operations are then repeated on this globe with air, and two orresponding weights p and P are obtained. The only correction ecessary is to reduce the weights in the two cases to the standard ressure by the method described in the preceding paragraph. The rrection for temperature is not needed, as the gas is at the temperature f melting ice. The ratio of the weight of the gas to that of the air is hus obtained by the formula

$$D = \frac{P_1 - p'}{P - p}.$$

311. **Density of gases which attack metals.**—For gases which tack the ordinary metals, such as chlorine, a metal stopcock cannot be sed, and vessels with ground glass stoppers are substituted. The gas is troduced by a bent glass tube, the vessel being held either upright or verted, according as the gas is heavier or lighter than air; when the essel is supposed to be full, the tube is withdrawn, the stopper inserted, he weight taken. This gives the weight of the vessel and gas. If apacity of the vessel be measured by means of water, the weight of ir which it contains is deduced, for the density of air at 0° C. and

760 millimeters pressure is $\frac{1}{773}$, that of distilled water under the same circumstances. The weight of the vessel full of air, less the weight of the contained air, gives the weight of the vessel itself. From these three data —the weight of the vessel full of the gas, the weight of the air which it contains, and the weight of the vessel alone—the specific gravity of the gas is readily deduced, the necessary corrections being made for temperature and pressure.

Density of gases at zero and at a pressure of 760 millimeters, that of air being taken as unity.

Air	1·0000	Sulphuretted hydrogen	1·1912
Hydrogen	0·0693	Hydrochloric acid	1·2540
Marsh gas	0·5590	Protoxide of nitrogen	1·5270
Ammoniacal gas	0·5367	Carbonic acid	1·5291
Carbonic oxide	0·9670	Cyanogen	1·8600
Nitrogen	0·9714	Sulphurous acid	2·2474
Binoxide of nitrogen	1·0360	Chlorine	3·4400
Oxygen	1·1057	Hydriodic acid	4·4430

Regnauld has furnished the following determinations of the weight of a litre of the most important gases at 0° C. and 760 mm. :—

Air	1·293187 grms.	Nitrogen	1·256167 grms.
Oxygen	1·429802	Carbonic acid	1·977414
Hydrogen	0·089578		

CHAPTER V.

CHANGES OF CONDITION. VAPOURS.

312. **Fusion. Its laws.**—The only phenomena of heat with which we have hitherto been engaged have been those of expansion. In the case of solids it is easy to see that this expansion is limited. For in proportion as a body absorbs a larger quantity of heat, the repulsive force between the molecules is increased, and ultimately a point is reached at which the molecular atraction is not sufficient to retain the body in the solid state. A new phenomenon is then produced : *fusion* takes place ; that is, the body passes from the solid into the liquid state.

Some substances, however, such as paper, wood, wool, and certain salts, do not fuse at a high temperature, but are decomposed. Many bodies have long been considered *refractory* ; that is, incapable of fusion; but, in proportion as it has been possible to produce higher temperatures, th number has diminished. Gaudin has succeeded in fusing rock crystal means of a lamp fed by a jet of oxygen ; and more recently Despretz, combining the effects of the sun, the voltaic battery, and the oxy-hyd ow-pipe, has melted alumina and magnesia, and softened carbon, be flexible, which is a condition near that of fusion.

s been experimentally found that the fusion of bodies is governed two following laws :—

very substance begins to fuse at a certain temperature, which is in-e for each substance if the pressure be constant.

Vhatever be the intensity of the source of heat, from the moment ommences, the temperature of the body ceases to rise, and remains t until the fusion is complete.

Fusing points of certain substances.

y	−38·8°	Sodium	90
e	−12·5°	Rose's fusible metal	94
	0	Sulphur	114
	+33	Tin	228
orus	44	Bismuth	264
ceti	49	Cadmium	321
um	55	Lead	335
ic acid	57	Zinc	422
e	60	Antimony	450
wax	65	Silver	1000
fusible metal	68·5	Gold	1250
acid	70	Iron	1500

substances pass from the solid to the liquid state without showing finite melting point; for example, glass and iron become gra-ofter and softer when heated, and pass by imperceptible stages e solid to the liquid condition. This intermediate condition is of as the state of *vitreous fusion*. Such substances may be said at the lowest temperature at which perceptible softening occurs, be fully melted when the further elevation of temperature does not em more fluid; but no precise temperature can be given as their points.

Influence of pressure on melting point.—Thomson and Clausius duced from the principles of the mechanical theory of heat that, increase of pressure, the melting point of a body must be raised. ies which expand on passing from the solid to the liquid state perform external work—namely, to raise the power of the atmo-by the amount of this expansion. Under ordinary circumstances, unt of external work which solids and liquids thus perform is so at it may be neglected. But if the external pressure be increased, ver of overcoming it can only be obtained by an increase of of the molecules. This increase can do more work; the tempera-fusion as well as the heat of fusion are both increased. Thus found that spermaceti, which melts at 48° under a pressure of phere, melts at 51° under a pressure of 156 atmospheres. Hopkins at spermaceti melted at 60° under a pressure of 519 atmospheres, and at 80° under 792 atmospheres; the melting point of sulphur under these pressures was respectively 135° and 141°.

But in the case of those bodies which contract on passing from the solid to the liquid state, and of which water is the best example, the reverse is the case. Melting ice has no external work to perform, since it has no external pressure to raise; on the contrary, in melting it assimilates external work which, transformed into heat, renders a smaller quantity of heat necessary; the external work acts in the same direction as the internal heat—namely, in breaking up the crystalline aggregates. Yet these differences of temperature must be but small, for the molecular forces in solids preponderate far over the external pressure; the internal work is far greater than the external.

Sir W. Thomson found that pressures of 8·1 and 16·8 atmospheres lowered the melting point of ice by 0·059° and 0·126° respectively. These results justify the theoretical previsions of Prof. T. Thomson, according to which an increase of pressure of n atmospheres lowers the melting point of ice by 0·0074n° C.

314. **Alloys. Fluxes.**—Alloys are generally more fusible than either of the metals of which they are composed; for instance, an alloy of five parts of tin and one of lead fuses at 194°. The alloy known as *Rose's fusible metal*, which consists of 4 parts of bismuth, 1 part of lead, and 1 of tin, melts at 94°, and an alloy of 1 or 2 parts of cadmium with 2 parts of tin, 4 parts of lead, and 7 or 8 parts of bismuth, known as *Wood's fusible metal*, melts between 66° and 71° C. Fusible alloys are of extended use in soldering and in taking casts. Steel melts at a lower temperature than iron, though it contains carbon, which is almost completely infusible.

Mixtures of the fatty acids melt at lower temperatures than the pure acids. A mixture of the chlorides of potassium and of sodium fuses at a lower temperature than either of its constituents; the same is the case with a mixture of the carbonates of potassium and sodium, especially when they are mixed in the proportion of their chemical equivalents.

An application of this property is met with in the case of *fluxes*, which are much used in metallurgical operations. They consist of substances which, when added to an ore, partly by their chemical action, help the reduction of the substance to the metallic state, and, partly by presenting a readily fusible medium, promote the formation of a regulus.

315. **Latent heat.**—Since, during the passage of a body from the solid to the liquid state, the temperature remains constant until the fusion is complete, whatever be the intensity of the source of heat, it must be concluded that, in changing their condition, bodies absorb a considerable amount of heat, the only effect of which is to maintain them in the liquid state. This heat, which is not indicated by the thermometer, is called *latent heat*, or *latent heat of fusion*, an expression which, though not in strict accordance with modern ideas, is convenient from the fact of its universal recognition and employment.

An idea of what is meant by latent heat may be obtained from the fol-

wing experiment. If a pound of water at 80° is mixed with a pound of
ter at zero, the temperature of the mixture is 40°. But if a pound of
unded *ice* at zero is mixed with a pound of water at 80°, the ice melts,
d two pounds of water at zero are obtained. Consequently, the mere
inge of a pound of ice to a pound of water at the same temperature re-
res as much heat as will raise a pound of water through 80°. This
antity of heat represents the latent heat of the fusion of ice, or the latent
it of water.

Every liquid has its own latent heat, and in the chapter on Calorimetry
shall show how this is determined.

16. **Solution.**—A body is said to *dissolve* when it becomes liquid in
isequence of an affinity between its molecules and those of a liquid.
m arabic, sugar, and most salts dissolve in water.

During solution, as well as during fusion, a certain quantity of heat
ays becomes latent, and hence it is that the solution of a substance
ally produces a diminution of temperature. In certain cases, however,
ead of the temperature being lowered, it actually rises, as when caustic
ass is dissolved in water. This depends upon the fact that two simul-
eous and contrary phenomena are produced. The first is the passage
n the solid to the liquid condition, which always lowers the tempera-
e. The second is the *chemical* combination of the body dissolved with
liquid, and which, as in the case of all chemical combinations, pro-
es an increase of temperature. Consequently, as the one or the other
hese effects predominates, or as they are equal, the temperature either
s, or sinks, or remains constant.

17. **Solidification.**—*Solidification* or *congelation* is the passage of a
ly from the liquid to the solid state. This phenomenon is regulated
the two following laws :—

. *Every body, under the same pressure, solidifies at a fixed temperature,
ich is the same as that of fusion.*

I. *From the commencement to the end of the solidification, the tempera-
e of a liquid remains constant.*

Certain bodies, more especially some of the fats, present an exception
the first law, in so far that by repeated fusions they seem to undergo
nolecular change which alters their melting point.

The second law is a consequence of the fact that the latent heat ab-
bed during fusion becomes free at the moment of solidification.

Many liquids, such as alcohol, ether, and bisulphide of carbon, do not
idify even at the lowest known temperature. But M. Despretz, by the
d produced by a mixture of liquid protoxide of nitrogen, solid carbonic
d, and ether, has reduced alcohol to such a consistence that the vessel
taining it could be inverted without losing the liquid.

18. **Crystallisation.**—Generally speaking, bodies which pass slowly
n the liquid to the solid state assume regular geometrical forms, such
the cube, prisms, rhombohedrons, &c. ; these are called *crystals*. If
crystals are formed from a body in fusion, such as sulphur or bismuth,
crystallisation is said to take place by the *dry way*. But if the crys-
isation takes place from the slow evaporation of a solution of a salt, it

said to be by the *moist way*. Snow, ice, and many salts present examples of crystallisation.

319. **Retardation of the point of solidification.**—The freezing poin of pure water can be diminished by several degrees, if the water be previously freed from air by boiling and then kept in a perfectly still place In fact it may be cooled to $-15°$ C., and even below, without freezing But when it is slightly agitated, the liquid soon solidifies. The smalle the quantity of liquid the lower the temperature to which it can be cooled and the greater the mechanical disturbance it supports without freezing Fournet has observed the frequent occurrence of mists formed of particles of liquid matter suspended in an atmosphere whose temperature is 10° or even 15° below zero.

A very rapid agitation also prevents the formation of ice. The same is the case with all actions which, hindering the molecules in their movements, do not permit them to arrange themselves in the conditions necessary for the solid state. M. Despretz was able to lower the temperature of water contained in fine capillary tubes to $-20°$ without their solidifying. This experiment shows how it is that plants in many cases do not become frozen, as the sap is contained in very fine capillary vessels. Finally, M. Mousson has found that a powerful pressure not only retards the freezing of water, but prevents its complete solidification. In this case the pressure opposes the tendency of the water to expand on freezing and thus virtually lowers the point of solidification.

If water contains salts or other foreign bodies its freezing point is lowered. Sea water freezes at $-2{\cdot}5°$ to $-3°$ C.; the ice which forms is quite pure, and a saturated solution remains. In Finland, advantage is taken of this property to concentrate sea water for the purpose of extracting salt from it. If water contains alcohol, precisely analogous phenomena are observed; the ice formed is pure, and all the alcohol is contained in the residue.

Dufour has observed some very curious cases of liquids cooled out of contact with solid bodies. His mode of experimenting was to place the liquid in another of the same specific gravity but of lower melting point, and in which it is insoluble. Spheres of water, for instance, suspended in a mixture of chloroform and oil, usually solidified between $-4°$ and $-12°$, while some smaller globules cooled down to $-18°$ or $-20°$. Contact with a fragment of ice immediately set up congelation. Globules of sulphur (which solidifies at 115°) remained liquid at 40°; and globules of phosphorus (solidifying point 42°) at 20°.

When a liquid solidifies after being cooled below its normal freezing point, the solidification takes place very rapidly, and is accompanied by a disengagement of heat, which is sufficient to raise its temperature from the point at which solidification begins up to its ordinary freezing point. This is well seen in the case of hyposulphite of sodium, which melts in its own water of crystallisation at 45°, and when carfeully cooled will remain liquid at the ordinary temperature of the atmosphere. If it then be made to solidify by agitation, or by adding a small fragment of the solid salt, e rise of temperature is distinctly felt by the hand. In this case the at which had become latent in the process of liquefaction again becomes e, and a portion of the substance remains melted; for it is kept liquid the heat of solidification of that which has solidified.

320. Change of volume on solidification and liquefaction.—The e of expansion of bodies generally increases as they approach their lting points, and is in most cases followed by a further expansion at e moment of liquefaction, so that the liquid occupies a greater volume an the solid from which it is formed. Phosphorus, for instance, increases out 3·4 per cent. on liquefaction; that is, 100 volumes of solid phosorus at 44° (the melting point) become 103·4 at the same temperature en melted. Sulphur expands about 5 per cent. on liquefying, and earic acid about 11 per cent.

Water presents a remarkable exception; it expands on the moment of lidifying, or contracts on melting, by about 10 per cent. One volume of e at 0° gives 0·9178 of water at 0°, or 1 volume of water at 0° gives 1·102 f ice at the same temperature. In consequence of this expansion, ice ats on the surface of water. According to Dufour the specific gravity f ice is 0·9178; Bunsen found for ice which had been freed from water y boiling the somewhat smaller number 0·91674.

The increase of volume in the formation of ice is accompanied by an pansive force which sometimes produces powerful mechanical effects, f which the bursting of water-pipes and the breaking of jugs containing ater are familiar examples. The splitting of stones, rocks, and the elling up of moist ground during frost, are caused by the fact that water netrates into the pores and there becomes frozen; in short, the great pansion of water on freezing is the most active and powerful agent of sintegration on the earth's surface.

The expansive force of ice was strikingly shown by some experiments of Major Williams, in Canada. Having quite filled a 13-inch iron bombshell with water, he firmly closed the touch-hole with an iron plug weighing 3 pounds, and exposed it in this state to the frost. After some time the iron plug was forced out with a loud explosion, and thrown to a distance of 415 feet, and a cylinder of ice 8 inches long issued from the opening. In another case the shell burst before the plug was driven out, and in this case a sheet of ice spread out all round the crack. It is possible that under the great pressure some of the water still remained liquid up to the time at which the resistance was overcome; that it then issued from the shell in a liquid state, but at a temperature below 0°, and therefore instantly began to solidify when the pressure was removed, and thus retained the shape of the orifice whence it issued.

Cast-iron, bismuth, and antimony expand on solidifying like water, and can thus be used for casting; but gold, silver, and copper contract, and hence coins of these metals cannot be cast, but must be stamped with a ie.

321. Freezing mixtures.—The absorption of heat in the passage of odies from the solid to the liquid state has been used to produce artificial cold. This is effected by mixing together bodies which have an affinit for each other, and of which one at least is solid, such as water and salt, ice and a salt, or an acid and a salt. Chemical affinity accelerate the fusion : the portion which melts robs the rest of the mixture of a larg quantity of sensible heat, which thus becomes latent. In many cases very considerable diminution of temperature is produced.

The following table gives the names of the substances mixed, their pr portions, and the corresponding diminutions of temperature :—

Substances.	Parts by weight.	Reduction of temperature.
Sulphate of sodium	8	+10° to −17°
Hydrochloric acid	5	
Pounded ice or snow	2	+10° to −18°
Common salt	1	
Sulphate of sodium	3	+10° to −19°
Dilute nitric acid	2	
Sulphate of sodium	6	+10° to −26°
Nitrate of ammonium	5	
Dilute nitric acid	4	
Phosphate of sodium	9	+10° to −29°
Dilute nitric acid	4	

If the substances taken be themselves first previously cooled down, a still more considerable diminution of temperature is occasioned.

Freezing mixtures are frequently used in chemistry, in physics, and in domestic economy. The portable ice-making machines which have come into use during the last few years consist of a cylindrical metallic vessel divided into four concentric compartments. In the central one is placed the water to be frozen ; in the next there is the freezing mixture, which usually consists of sulphate of sodium and hydrochloric acid ; 6 pounds of the former and 5 of the latter will make 5 to 6 pounds of ice in an hour. The third compartment also contains water, and the outside one contains some badly-conducting substance, such as cotton, to prevent the influence of the external temperature. The best effect is obtained when pretty large quantities (2 or 3 pounds) of the mixture are used, and when they are intimately mixed. It is also advantageous to use the machines for a series of successive operations.

VAPOURS. MEASUREMENT OF THEIR TENSION.

322. **Vapours.**—We have already seen (141) that *vapours* are the aëriform fluids into which volatile substances, such as ether, alcohol, water, and mercury, are changed by the absorption of heat. *Volatile liquids* are those which thus possess the property of passing into the aëriform state, and *fixed liquids*, those which do not form vapours at any temperature without undergoing chemical decomposition, such as the fatty oils. There are some solids, such as ice, arsenic, camphor, and in

l all odoriferous solid substances, which can directly form vapours t first becoming liquid.

ours are transparent like gases, and generally colourless : there are few coloured liquids, which also give coloured vapours.

Vaporisation.—The passage of a liquid into the gaseous state is ated by the general term *vaporisation*; the term *evaporation* espe- refers to the slow production of vapour at the free surface of a , and *boiling* to its rapid production in the mass of the liquid itself. all presently see (336) that at the ordinary atmospheric pressure, ion, like fusion, takes place at a definite temperature. This is not se with evaporation, which takes place even with the same liquid at ifferent temperatures, although the formation of a vapour seems se below a certain point. Mercury, for example, gives no vapour – 10°, nor sulphuric acid below 30°.

. **Elastic force of vapours.**—Like gases, vapours have a certain : force, in virtue of which they exert pressures on the sides of s in which they are contained. The tension ours may be demonstrated by the following ment :—A quantity of mercury is placed in a lass tube (fig. 254), the shorter leg of which sed ; a few drops of ether are then passed he closed leg, and the tube immersed in a bath at a temperature of about 45°. The ry then sinks slowly in the short branch, and ace *ab* is filled with a gas which has all the rance of air, and whose elastic force counter- es the pressure of the column of mercury *cd*, e atmospheric pressure on *d*. This gas is pour of ether. If the water be cooled, or if be be removed from the bath, the vapour fills the space *ab* disappears, and the drop of s reproduced. If, on the contrary, the bath ated still higher, the level of the mercury ds below *b*, indicating an increased tension.

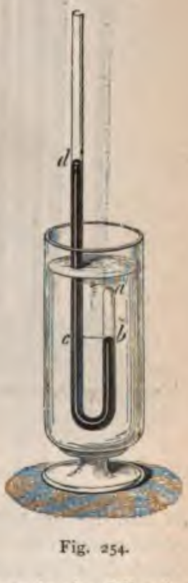


Fig. 254.

Formation of vapours in a vacuum.—In evious experiment the liquid changed very into the vaporous condition ; the same is the hen a liquid is freely exposed to the air. In ases the atmosphere is an obstacle to the sation. In a vacuum there is no resistance, e formation of vapours is instantaneous, as is seen in the following nent :—Four barometer tubes, filled with mercury, are immersed same trough (fig. 255). One of them, A, serves as a barometer, few drops of water, alcohol, and ether are respectively introduced e tubes, B, C, D. When the liquids reach the vacuum, a depres- f the mercury is at once produced. And as this depression be produced by the weight of the liquid, which is an infinitely fraction of the weight of the displaced mercury, it must be due to the formation of some vapour whose elastic force has depress mercurial column.

The experiment also shows that the depression is not the same the tubes; it is greater in the case of alcohol than of water, and with ether than with alcohol. We consequently obtain the two fol laws for the formation of vapours :—

I. *In a vacuum all volatile liquids are instantaneously convert vapour.*

II. *At the same temperature the vapours of different liquid different elastic forces.*

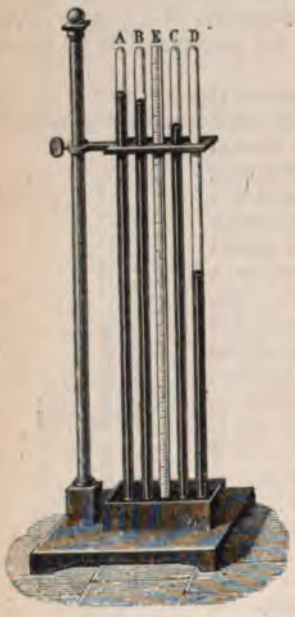


Fig. 255.

For example, at 20° the tension o vapour is 25 times as great as t aqueous vapour.

326. **Saturated vapours. Ma of tension.**—When a very small q of a volatile liquid, such as ether, i duced into a barometer tube, it is completely vaporised, and the me column is not depressed to its full for if some more ether be introdu depression increases. By continu addition of ether, it finally ceases porise, and remains in the liqui There is, therefore, for a certain rature, a limit to the quantity of which can be formed in a given This space is accordingly said *saturated.* Further, when the va tion of the ether ceases, the depre the mercurial column stops. And there is a limit to the tension vapour, a limit which, as we sh sently see (329), varies with the te ture, but which for a given temp is *independent of the pressure.*

To show that, in a closed space ated with vapour and containing *in excess,* the temperature remaining constant, there is a *ma of tension* which the vapour cannot exceed, a barometric tube which dips in a deep bath (fig. 256). This tube is filled with merc then so much ether is added as to be in excess after the Tor vacuum is saturated. The height of the mercurial column is ne by means of the scale graduated on the tube itself. Now, whe tube be depressed, which tends to compress the vapour, or wheth raised, which tends to expand it, the height of the mercurial co constant. The tension of the vapour remains constant in the tw for the depression neither increases nor diminishes it. Hen concluded that when the saturated vapour is compressed, a por the liquid state; that when, on the other hand, the pressure is hed, a portion of the excess of liquid vaporises, and the space d by the vapour is again saturated; but in both cases the tension density of the vapour remain constant.

Non-saturated vapours.—From what has been said, vapours two very different states, according as they are saturated or not. irst case, where they are saturated and in contact with the liquid, fer completely from gases, since for a given temperature they can be compressed nor expanded; their elastic force and their den-ıain constant.

e second case, on the contrary, where they are not saturated, they resemble gases. For if the experiments (fig. 256) be repeated,

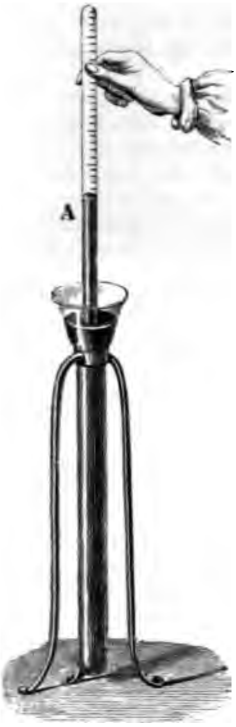


Fig. 256.

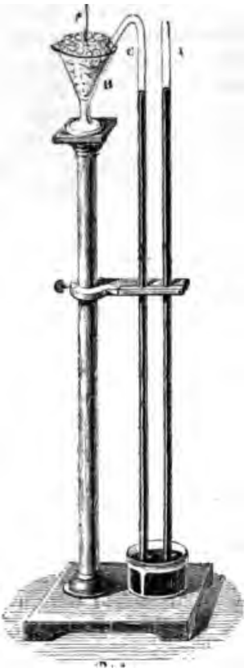


Fig. 257.

a small quantity of ether being introduced, so that the vapour is aturated, and if the tube be then slightly raised, the level of the ıry is seen to rise, which shows that the elastic force of the vapour has diminished. Similarly, by immersing the tube still more, the level of the mercury sinks. The vapour consequently behaves just as a gas would do, its tension diminishes when the volume increases, and *vice versâ* ; and as in both cases the volume of the vapour is inversely as the pressure, it is concluded that *non-saturated vapours obey Boyle's law.*

When a non-saturated vapour is heated, its volume increases like that of a gas : and the number 0·00366, which is the coefficient of the expansion of air, may be taken for that of vapours.

Hence we see that the physical properties of unsaturated vapours are comparable with those of permanent gases, and that the formulæ for the compressibility and expansibility of gases (166 and 306) also apply to unsaturated vapours. But it must not be forgotten that there is always a limit of pressure or of cooling at which unsaturated vapours pass into a state of saturation, and that they have then a maximum of tension and density which can only be exceeded when the temperature rises while they are in contact with the liquid.

328. **Tension of aqueous vapours below zero.**—For the sake of measuring the elastic force of aqueous vapour below zero, Gay-Lussac used two barometer tubes filled with mercury, and placed in the same bath (fig. 257). The straight tube A serves as a barometer; the other, B, is bent, so that part of the Torricellian vacuum can be surrounded by a freezing mixture (321). When a little water is admitted into the bent tube, the level of the mercury sinks below that in the tube A to an extent which varies with the temperature of the freezing mixture.

At 0°	the depression is	4·94 millimeters.
„ −10°	„ „	2·08 „
„ −20°	„ „	0·84 „
„ −30°	„ „	0·36 „

These depressions, which must be due to the tension of aqueous vapour in the space BC, show that even at very low temperatures there is always some aqueous vapour in the atmosphere.

Although in the above experiment the part B and the part C are not both immersed in the freezing mixture, we shall presently see that when two communicating vessels are at different temperatures, the tension of the vapour is the same in both, and always corresponds to that of the lowest temperature.

That water evaporates even below zero follows from the fact, that wet linen exposed to the air during frost first becomes stiff and then dry, showing that the particles of water evaporate even after the latter has been converted into ice.

329. **Tension of aqueous vapour between zero and one hundred degrees.**—i. *Dalton's method.* Dalton measured the elastic force of aqueous vapour between 0° and 100° by means of the apparatus represented in fig. 258. Two barometer tubes, A and B, are filled with mercury, and inverted in an iron bath full of mercury, and placed on a furnace. The tube A contains a small quantity of water. The tubes are supported in a cylindrical vessel full of water, the temperature of which is indicated

e thermometer. The bath being gradually heated, the water in the der becomes heated too; the water which is in the tube A vaporises, n proportion as the tension of its vapour increases, the mercury . The depressions of the mercury corresponding to each degree of ermometer are indicated on the scale E, and in this manner a table elastic forces between zero and 100° has been constructed.

Regnault's method.—Dalton's method is wanting in precision, for quid in the cylinder has not everywhere the same temperature, and quently the exact temperature of the aqueous vapour is not indicated.

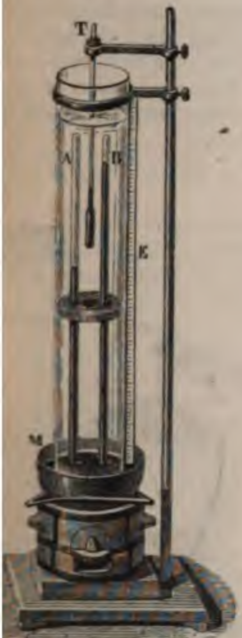


Fig. 258.

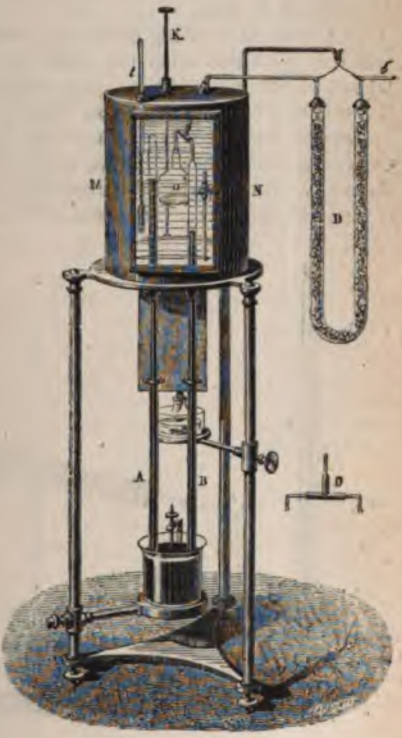


Fig. 259.

ault's apparatus is a modification of that of Dalton. The cylindrical is replaced by a large cylindrical zinc drum, MN (fig. 259), in the n of which are two tubulures. The tubes A and B pass through these ires, and are fixed by caoutchouc collars. The tube containing r, B, is connected with a flask, *a*, by means of a brass three-way tube, O. The third limb of this tube is connected with a drying tube, containing pumice impregnated with sulphuric acid, which is connect with the air pump.

When the flask *a* contains some water, a small portion is distilled B by gently heating the flask. Exhausting them by means of the pump, the water distils continuously from the flask and from the metric tube towards D, which condenses the vapours. After ha vaporised some quantity of water, and it is thought that the air tube is withdrawn, the capillary tube which connects B with the three- tube is sealed. The tube B being thus closed, it is experimented with, in Dalton's method.

The drum MN, being filled with water, is gently heated by a spirit la which is separated from the tubes by a wooden screen. By means stirrer, K, all parts of the liquid are kept at the same temperature. the side of the drum is a glass window, through which the height of mercury in the tubes can be read off by means of a cathetometer; fr the difference in these heights, reduced to zero, the tension of vapo deduced. By means of this apparatus, the elastic force of vapour betw 0° and 50° has been determined with accuracy.

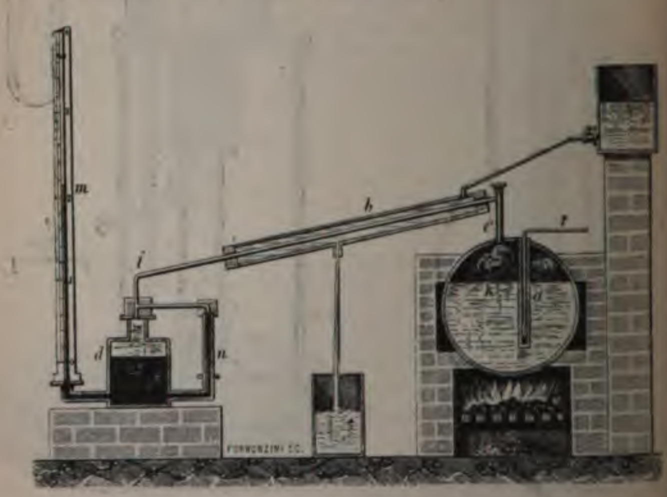


Fig. 260.

330. Tension of aqueous vapour above one hundred degrees.— methods have been employed for determining the tension of aque vapour at temperatures above 100°, the one by Dulong and Arago, in th and the other by Regnault, in 1844.

Fig. 260 represents a vertical section of the apparatus used by Dul and Arago. It consisted of a copper boiler, *k*, with very thick sides, of about 20 gallons capacity. Two gun-barrels, *a*, of which only seen in the drawing, were firmly fixed in the sides of the boiler, and plunged in the water. The gun-barrels were closed below, and contained mercury, in which were placed thermometers, *t*, indicating the temperature of the water and of the vapour. The tension of the vapour was measured by means of a manometer with compressed air, *m*, previously graduated (171) and fitted into an iron vessel, *d*, filled with mercury. In order to see the height of the mercury in the vessel, it was connected above and below with a glass tube, *n*, in which the level was always the same as in the bath. A copper tube, *i*, connected the upper part of the vessel, *d*, with a vertical tube, *c*, fitted in the boiler. The tube *i* and the upper part of the bath *d* were filled with water, which was kept cool by means of a current of cold water flowing from a reservoir and circulating through the tube *b*.

The vapour which was disengaged from the tube *c* exercised a pressure on the water of the tube *i*; this pressure was transmitted to the water and to the mercury in the bath *d*, and the mercury rose in the manometer. By noting on the manometer the pressures corresponding to each degree of the thermometer, Dulong and Arago were able to make a direct measurement of the tension up to 24 atmospheres, and the tension from thence to 50 atmospheres was determined by calculation.

331. **Tension of vapour below and above one hundred degrees.**—Regnault has devised a method by which the tension of vapour may be measured at temperatures either below or above 100°. It depends on the principle that when a liquid boils, the tension of the vapour is equal to the pressure it supports (336). If, therefore, the temperature and the corresponding pressure are known, the question is solved, and the method merely consists in causing water to boil in a vessel under a given pressure, and measuring the corresponding temperature.

The apparatus consists of a copper retort, C (fig. 261), hermetically sealed, and about two-thirds full of water. In the cover there are four thermometers, two of which just dip into the water, and two descend almost to the bottom. By means of a tube, AB, the retort C is connected with a glass globe, M, of about 6 gallons capacity, and full of air. The tube AB passes through a metallic cylinder, D, through which a current of cold water is constantly flowing from the reservoir E. To the upper part of the globe a tube with two branches is attached, one of which is connected with a manometer, O; the other tube, HH′, which is of lead, can be attached either to an exhausting or a condensing air pump, according as the air in the globe is to be rarefied or condensed. The reservoir K, in which is the globe, contains water of the temperature of the surrounding air.

If the elastic force of aqueous vapour below 100° is to be measured, the end H′ of the leaden pipe is connected with the plate of the air pump, and the air in the globe M, and consequently that in the retort C, is rarefied. The retort being gently heated, the water begins to boil at a temperature below 100°, in consequence of the diminished pressure. And since the vapour is condensed in the tube AB, which is always cool, the pressure originally indicated by the manometer does not increase, therefore the tension of the vapour during ebullition remains equal to pressure on the liquid.

A little air is then allowed to enter; this alters the pressure, and liquid boils at a new temperature; both these are read off, and the periment repeated as often as desired up to 100°.

In order to measure the tension above 100°, the tube H′ is conne

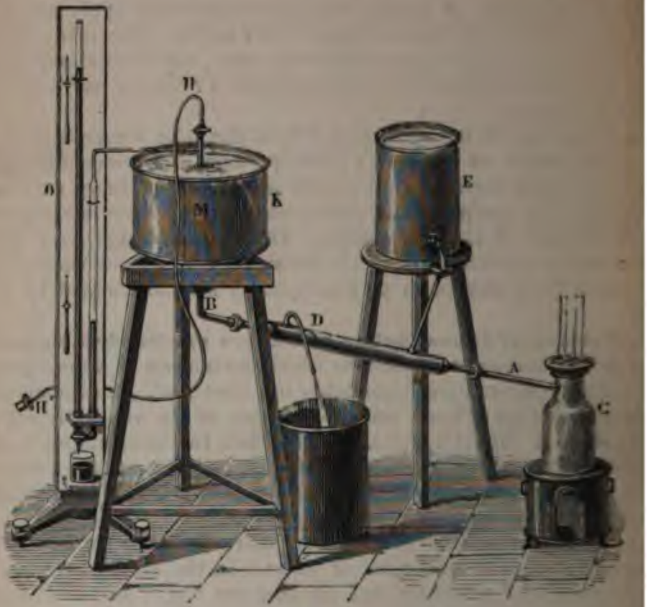


Fig. 261.

with a condensing pump, by means of which the air in the globe M that in the vessel C are exposed to successive pressures, higher than atmospheres. The ebullition is retarded (339), and it is only neces to observe the difference in the height of the mercury in the two tube the manometer O, and the corresponding temperature, in order to ob the tension for a given temperature.

The following tables by M. Regnault give the tension of aque vapour from −10° to 101°.

Tensions of aqueous vapour from −10° *to* 101° *C.*

Tempera-tures	Tensions in milli-meters	Tempera-tures	Tensions in millimeters	Tempera-tures	Tensions in millimeters	Tempera-tures	Tensions in millimeters
−10°	2·078	12°	10·457	29°	29·782	85°	433·41
8	2·456	13	11·062	30	31·548	90	525·45
6	2·890	14	11·906	31	33·405	91	545·78
4	3·387	15	12·699	32	35·359	92	566·76
2	3·955	16	13·635	33	37·410	93	588·41
0	4·600	17	14·421	34	39·565	94	610·74
+ 1	4·940	18	15·357	35	41·827	95	633·78
2	5·302	19	16·346	40	54·906	96	657·54
3	5·687	20	17·391	45	71·391	97	682·03
4	6·097	21	18·495	50	91·982	98	707·26
5	6·534	22	19·659	55	117·478	98·5	720·15
6	6·998	23	20·888	60	148·791	99·0	733·21
7	7·492	24	22·184	65	186·945	99·5	746·50
8	8·017	25	23·550	70	233·093	100·0	760·00
9	8·574	26	24·998	75	288·517	100·5	773·71
10	9·165	27	26·505	80	354·643	101·0	787·63
11	9·792	28	28·101				

In the second table the numbers were obtained by direct observation to 24 atmospheres; the others were calculated by the aid of a formula interpolation.

Tensions in atmospheres from 100° *to* 230·9°.

Temperature	Number of atmospheres	Temperature	Number of atmospheres	Temperature	Number of atmospheres	Temperature	Number of atmospheres
100·0°	1	170·8°	8	198·8°	15	217·9°	22
12·2	1½	175·8	9	201·9	16	220·3	23
120·6	2	180·3	10	204·9	17	222·5	24
133·9	3	184·5	11	207·7	18	224·7	25
144·0	4	188·4	12	210·4	19	226·8	26
152·2	5	192·1	13	213·0	20	228·9	27
159·2	6	195·5	14	215·5	21	230·9	28
165·3	7						

These tables show that the elastic force increases much more rapidly an the temperature. The law which regulates this increase is not curately known.

332. **Tension of the vapours of different liquids.**—Regnault has

determined the elastic force at various temperatures of a certain number of liquids which are given in the following table :—

Liquids	Temperature	Tensions in millimeters	Liquids	Temperature	Tensions in millimeters
Mercury .	50°	0·11	Ether . .	−20°	68
	100	0·74		0	182
Alcohol .	0	13		60	1728
	50	220		100	4950
	100	1695	Sulphurous acid	−20	479
Bisulphide of carbon	−20	43		0	1165
	0	132		60	8124
	60	1164	Ammonia	−30	876
	100	3329		0	3163
				30	8832

333. **Tension of the vapours of mixed liquids.**—Regnault's experiments on the tension of the vapour of mixed liquids prove that (i.) when two liquids exert no solvent action on each other—such as water and *bisulphide of carbon*, or water and *benzole*—the tension of the vapour which rises from them is nearly equal to the sum of the tensions of the two separate liquids at the same temperature; (ii.) with water and *ether*, which partially dissolve each other, the tension of the mixture is much less than the sum of the tensions of the separate liquids, being scarcely equal to that of the ether alone: (iii.) when two liquids dissolve in all proportions, as ether and bisulphide of carbon, or water and alcohol, the tension of the vapour of the mixed liquid is intermediate between the tensions of the separate liquids.

Wüllner has shown that the tension of aqueous vapour emitted from a saline solution, as compared with that of pure water, is diminished by an amount proportional to the quantity of anhydrous salt dissolved, when the salt crystallises without water or yields efflorescent crystals; when the salt is deliquescent, or has a powerful attraction for water, the reduction of tension is proportional to the quantity of crystallised salt.

334. **Tension in two communicating vessels at different temperatures.** When two vessels containing the same liquid, but at different temperatures, are connected with each other, the elastic force is not that corresponding to the mean of the two temperatures, as would naturally be supposed. Thus, if there are two globes, fig. 257, one, A, containing water kept at zero by means of melting ice, the other, B, containing water at 100°, the tension, as long as the globes are not connected, is 4 to 6 millimeters in the first, and 760 millimeters in the second. But when they are connected by opening the stopcock C, the vapour in the globe B, from its greater tension, passes into the other globe, and is there condensed, so that the vapour in B can never reach a higher temperature than that in the globe A. The liquid simply distils from B towards A without any increase of tension.

m this experiment the general principle may be deduced that *when ssels containing the same liquid, but at different temperatures, are ted, the tension is identical in both vessels, and is the same as that onding to the lower temperature.* An application of this principle en made by Watt in the condenser of the steam-engine.

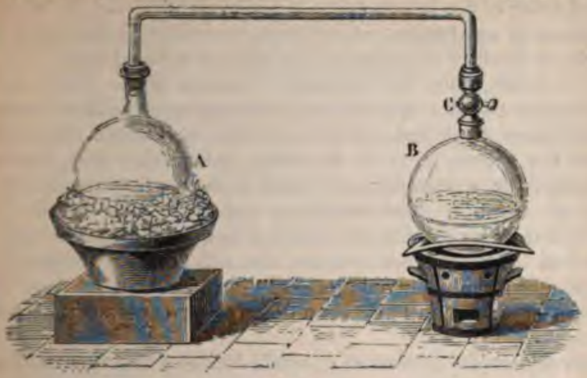


Fig. 262.

Evaporation. Causes which accelerate it.—*Evaporation*, as een already stated (323), is the slow production of vapour at the e of a liquid. It is in consequence of this evaporation that wet s dry when exposed to the air, nat open vessels containing water ne emptied. The vapours which, in the atmosphere, condense, ecoming clouds fall as rain, are the evaporation from the seas, rivers, and the soil.

ır causes influence the rapidity of aporation of a liquid : i. the temre; ii. the quantity of the same r in the surrounding atmosphere; e renewal of this atmosphere; extent of the surface of evapo-

rease of temperature accelerates vaporation by increasing the force of the vapours.

rder to understand the influence second cause, it is to be ob- that no evaporation could take n a space already saturated with of the same liquid, and that it reach its maximum in air completely freed from this vapour. It re follows that between these two extremes the rapidity of evapo-

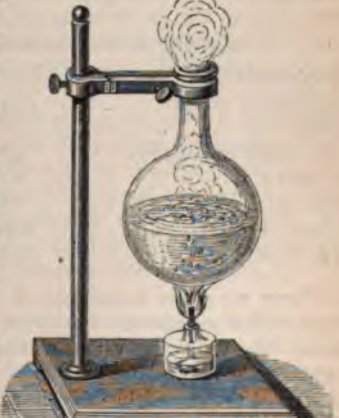


Fig. 263.

ration varies according as the surrounding atmosphere is already mo less charged with the same vapour.

The effect of the renewal of this atmosphere is similarly explained the air or gas, which surrounds the liquid, is not renewed, it becomes saturated, and evaporation ceases.

The influence of the fourth cause is self-evident.

336. **Laws of ebullition.**—*Ebullition*, or *boiling*, is the rapid pr tion of elastic bubbles of vapour in the mass of a liquid itself.

When a liquid, water for example, is heated at the lower part vessel, the first bubbles are due to the disengagement of air which previously been absorbed. Small bubbles of vapour then beg rise from the heated parts of the sides, but as they pass throug upper layers, the temperature of which is lower, they condense b reaching the surface. The formation and successive condensati these first bubbles, occasion the *singing* noticed in liquids before begin to boil. Lastly, large bubbles rise and burst on the surface this constitutes the phenomenon of ebullition (fig. 263).

The laws of ebullition have been determined experimentally, an as follows :—

I. *The temperature of ebullition, or the boiling point, increases wi pressure.*

II. *For a given pressure ebullition commences at a certain temper which varies in different liquids, but which, for equal pressures, is al the same in the same liquid.*

III. *Whatever be the intensity of the source of heat, as soon as e tion commences, the temperature of the liquid remains stationary.*

Boiling points under the pressure 760 *millimeters.*

Sulphurous acid	−10°	Turpentine
Chloride of ethyle	+11	Butyric acid
Ether	37	Phosphorus
Bisulphide of carbon	48	Strong sulphuric acid
Bromine	63	Mercury
Alcohol	78	Sulphur
Distilled water	100	Cadmium
Acetic acid	117	Zinc

There are many causes which influence the boiling point of a l such as the substances dissolved, the nature of the vessel, and the sure. We shall illustrate the effects of these different causes, more ticularly on water

Kopp has pointed out that in analogous chemical compounds the difference in chemical composition frequently involves the same diffe of boiling points; and he has endeavoured to show that in a ve tensive series of compounds the difference of CH^2 is attended by a ence of 19° C. in the boiling point.

337. **Influence of substances in solution on the boiling po** The ebullition of a liquid is the more retarded the greater the qu

of any substance it may contain in solution, provided that the substance be not volatile, or, at all events, be less volatile than the liquid itself. Water which boils at 100° when pure, boils at the following temperatures when saturated with different salts :—

Water saturated with		common salt . .	boils at	109°
"	"	nitrate of potassium	"	116
"	"	carbonate of potassium	"	135
"	"	chloride of calcium	"	179

Acids in solution present analogous results; but substances merely mechanically suspended, such as earthy matters, bran, wooden shavings, etc., do not affect the boiling point.

Dissolved air exerts a very marked influence on the boiling point of water. Deluc first observed that water freed from air by ebullition, and placed in a flask with a long neck, could be raised to 112° without boiling. M. Donny found that water deprived of air and sealed up in a long glass tube may be heated at one end as high as 138° without boiling, and is then suddenly and violently thrown to the other by a burst of vapour.

When a liquid is suspended in another of the same specific gravity, but higher boiling point, with which it does not mix, it may be raised far beyond its boiling point without the formation of a trace of vapour. Dufour has made a number of valuable experiments on this subject; he used in the case of water a mixture of oil of cloves and linseed oil, and placed in it globules of water, and then gradually heated the oil; in this way ebullition rarely set in below 110° or 115°, very commonly globules of 10 millimeters diameter reached a temperature of 120° or 130°, while very small globules of 1 to 3 millimeters reached the temperature of 175°, a temperature at which the tension of vapour on a free surface is 8 or 9 atmospheres.

At these high temperatures the contact of a solid body, or the production of gas bubbles in the liquid, occasioned a sudden vaporisation of the globule, accompanied by a sound like the hissing of a hot iron in water.

Saturated aqueous solutions of sulphate of copper, chloride of sodium, etc., remained liquid at a temperature far beyond their boiling point, when mmersed in melted stearic acid. In like manner, globules of chloroform (which boils at 61°) suspended in a solution of chloride of zinc could be heated to 97° or 98° without boiling.

It is a disputed question as to what is the temperature of the vapour rom boiling saturated saline solutions. It has been stated by Rudberg o be that of pure water boiling under the same pressure; the most recent xperiments of Magnus seem to show, however, that this is not the case, ut that the vapour of boiling solutions is hotter than that of pure ater; and that the temperature rises as the solutions become more ncentrated, and therefore boil at higher temperatures. Nevertheless, he vapour was always found somewhat cooler than the mass of the oiling solution, and the difference was greater at high than at low emperatures.

The boiling point of a liquid is usually lowered when it is mix
more volatile liquid than itself, but raised when it contains one
less volatile. Thus a mixture of two parts alcohol and one
boils at 83°, a mixture of two parts of bisulphide of carbon and
of ether boils at 38°. In some cases the boiling point of a m
lower than that of either of its constituents. A mixture of w
bisulphide boils at 43°, the boiling point of the latter being 46°.
depends the following curious experiment. If water and bisul
carbon, both at the temperature 45°, are mixed together, the m
once begins to boil briskly.

338. **Influence of the nature of the vessel on the boiling**
Gay-Lussac observed that water in a glass vessel required
temperature for ebullition than in a metal one. Taking the ten
of boiling water in a copper vessel at 100°, its boiling point i
vessel was found to be 101°; and if the glass vessel had been p
cleaned by means of sulphuric acid and of potass, the temperatu
rise to 105°, or even to 106°, before ebullition commenced. A
metal placed in the bottom of the vessel was always sufficient
the temperature to 100°, and at the same time to prevent the vio
cussions which accompany the ebullition of saline or acid sol
glass vessels. Whatever be the boiling point of water, the temp
its vapour is uninfluenced by the substance of the vessels.

339. **Influence of pressure on the boiling point.**—We see
table of tensions (331) that at 100°, the temperature at which w
under a pressure of 760 mi
aqueous vapour has a te
actly equal to this pressu
principle is general, and
thus enunciated: *A liq*
when the tension of its v
equal to the pressure it
Consequently, as the pre
creases or diminishes, th
of the vapour, and then
temperature necessary f
tion, must increase or dim

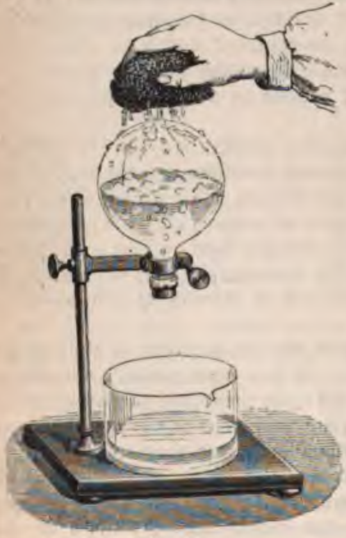


Fig. 264.

In order to show that
ing point is lower under di
pressure, a small dish c
water at 30° is placed
receiver of an air pump,
then exhausted. The lic
begins to boil, the vapou
being pumped out as ra
is generated.

A paradoxical but ve
experiment also well illus
dependence of the boiling point on the pressure. In a glass fl

is boiled for some time, and when all air has been expelled by the steam, the flask is closed by a cork and inverted as shown in fig. 264. If the bottom is then cooled by a stream of cold water from a sponge, the water begins to boil again. This arises from the condensation of the steam above the surface of the water, by which a partial vacuum is produced.

It is in consequence of this diminution of pressure that liquids boil on high mountains at lower temperatures. On Mont Blanc, for example, water boils at 84°, and at Quito at 90°.

On the more rapid evaporation of water under feeble pressures is based the use of the air pump in concentrating those solutions which either cannot bear a high degree of heat, or which can be more cheaply evaporated in an exhausted space. Mr. Howard made a most important and useful application of this principle in the manufacture of sugar. The syrup, in his method, is enclosed in an air-tight vessel, which is exhausted by a steam-engine. The evaporation consequently goes on at a lower temperature, which secures the syrup from injury. The same plan is adopted in evaporating the juice of certain plants used in preparing medicinal extracts.

On the other hand, ebullition is retarded by increasing the pressure; under a pressure of two atmospheres, for example, water only boils at 120·6°.

340. **Franklin's experiment.**—The influence of pressure on ebullition may further be illustrated by means of an experiment of Franklin's. The apparatus consists of a bulb, *a*, and a tube, *b*, joined by a tube of smaller dimensions (fig. 265). The tube *b* is drawn out, and the apparatus filled with water, which is then in great part boiled away by means of a spirit lamp. When it has been boiled sufficiently long to expel all the air, the tube *b* is sealed. There is then a vacuum in the apparatus, or rather there is a pressure due to the tension of aqueous vapour, which at ordinary temperatures is very small. Consequently, if the bulb *a* be placed in the hand, the heat is sufficient to produce a tension which drives the water into the tube *b*, and causes a brisk ebullition.

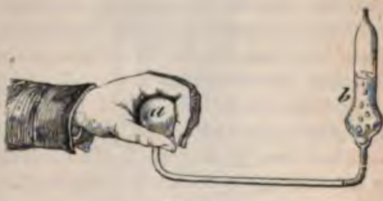


Fig. 265.

341. **Measurement of heights by the boiling point.**—From the connection between the boiling point of water and the pressure, the heights of mountains may be measured by the thermometer instead of by the barometer. Suppose, for example, it is found that water boils on the summit of a mountain at 90°, and at its base at 98°; at these temperatures the elastic force or tension of the vapour is equal to that of the pressure on the liquid, that is, to the pressure of the atmosphere at the two places respectively. Now the tensions of aqueous vapour for various temperatures have been determined, and accordingly the tensions corre-

sponding to the above temperatures are sought in the tables. These numbers represent the atmospheric pressures at the two places : in other words, they give the barometric heights, and from these the height of the mountain may be calculated by the method already given (165). An ascent of about 1080 feet produces a diminution of 1° C. in the boiling point.

The instruments used for this purpose are called *thermo-barometers*, or *hypsometers*, and were first applied by Wollaston. They consist essentially of a small metallic vessel for boiling water, fitted with very delicate thermometers, which are only graduated from 80° to 100°; so that each degree occupying a considerable space on the scale, the 10ths, and even the 100ths, of a degree may be estimated, and thus it is possible to determine the height of a place by means of the boiling point to within about 10 feet.

342. **Formation of vapour in a closed tube.**—We have hitherto considered vapours as being produced in an indefinite space, or where they could expand freely, and it is only under this condition that ebullition can take place. In a closed vessel the vapours produced finding no issue, their tension and their density increase with the temperature, but the rapid disengagement of vapour which constitutes ebullition is impossible. Hence, while the temperature of a liquid in an open vessel can never exceed that of ebullition, in a closed vessel it may be much higher. The liquid state has, nevertheless, a limit ; for, according to experiments by Cagniard-Latour, if either water, alcohol, or ether be placed in strong glass tubes, which are hermetically sealed after the air has been expelled by boiling, when these tubes are exposed to a sufficient degree of heat, a moment is reached at which the liquid suddenly disappears, and is converted into vapour at 200°, occupying a space less than double its volume in the liquid state, and that the tension was then 38 atmospheres.

Alcohol which half fills a tube is converted into vapour at 207° C. If a glass tube about half filled with water, in which some carbonate of soda has been dissolved, to diminish the action of the water in the glass, be heated, it is completely vaporised at about the temperature of melting zinc.

When chloride of ethyle was heated in a very thick sealed tube, the upper surface ceased to be distinct at 170°, and was replaced by an ill-defined nebulous zone. As the temperature rose this zone increased in width in both directions, becoming at the same time more transparent; after a time the liquid was completely vaporised, and the tube became transparent and seemingly empty. On cooling, the phenomena were reproduced in the opposite order. Similar appearances were observed on heating ether in a sealed tube at 190°.

Andrews has observed that when liquid carbonic acid was heated in a closed tube to 31° C. the surface of demarcation between the liquid and the gas became fainter, lost its curvature, and gradually disappeared. The space was then occupied by a homogeneous fluid, which, when the pressure was suddenly diminished, or the temperature slightly lowered, xhibited a peculiar appearance of moving or flickering striæ throughout ts whole mass. Above 30° no apparent liquefaction of carbonic anhydride, or separation into two distinct forms of matter, could be effected, ot even when the pressure of 400 atmospheres was applied. It would thus eem that there exists for every liquid a temperature, the *critical* temperature. While below this critical point a sudden transition from gas to iquid is accompanied by a sudden diminution of volume, and liquid and as are separated by a sharp line of demarcation; above this critical oint the change is connected with a gradual diminution of volume, and s quite imperceptible. The condensation can, indeed, only be recognised y a sudden ebullition when the pressure is lessened. Hence, ordinary ondensation is only possible below the critical point, and it is not urprising, therefore, that mere pressure, however great, should fail to iquefy many of the bodies which usually exist as gases.

343. **Papin's digester.**—Papin, a French physician, appears to have een the first to study the effects of the productions of vapour in closed essels. The apparatus which bears his name consists of a cylindrical ron vessel (fig. 266), provided with a cover, which is firmly fastened down y the screw B. In order to close he vessel hermetically, sheet lead is placed between the edges of the cover and the vessel. At the bottom of a cylindrical cavity, which traverses the cylinder S, and the tubulure *o*, the cover is perforated by a small orifice n which there is a rod, *n*. This rod presses against a lever, A, movable at *a*, and the pressure may be regulated by means of a weight movable on this lever. The lever is so weighted, that when the tension in the interior is equal to 6 atmospheres, for example, the valve rises and the vapour escapes. The destruction of the apparatus is thus avoided, and the mechanism has hence received the name of *safety valve*. The digester is filled about two-thirds with water, and is heated on a furnace. The water may thus be raised to a temperature far above 100°, and the tension of the vapour ncreased to several atmospheres, according to the weight on the lever.

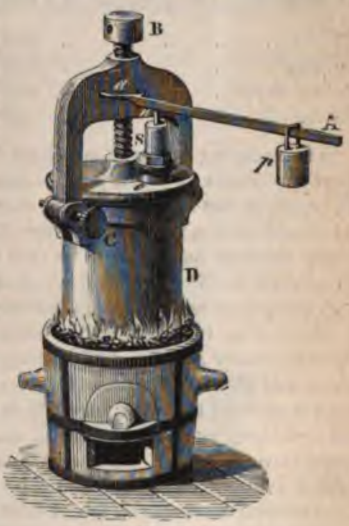


Fig. 266.

We have seen that water boils at much lower temperatures on high ountains (339); the temperature of water boiling in open vessels in uch localities is not sufficient to soften animal fibre completely and xtract the nutriment, and hence Papin's digester is used in the preration of food.

Papin's digester is used in extracting gelatine. When bones are digested in this apparatus they are softened so that the gelatine which they contain is dissolved.

344. **Latent heat of vapour.**—As the temperature of a liquid remains constant during ebullition, whatever be the source of heat (336), it follows that a considerable quantity of heat becomes absorbed in ebullition, the only effect of which is to transform the body from the liquid to the gaseous condition. And conversely when a saturated vapour passes into the state of liquid, it gives out an amount of heat.

These phenomena were first observed by Black, and he described them by saying that during vaporisation a quantity of sensible heat became latent, and that the latent heat again became free during condensation. The quantity of heat which a liquid must absorb in passing from the liquid to the gaseous state, and which it gives out in passing from the state of vapour to that of liquid, is spoken of as the *latent heat of evaporation.*

The analogy of these phenomena to those of fusion will be at once seen; the modes of determining them will be described in the chapter on Calorimetry; but the following results, which have been obtained for the latent heats of evaporation of a few liquids, may be here given :—

Water	536	Bisulphide of carbon	87
Alcohol	208	Turpentine	74
Acetic acid	102	Bromine	46
Ether	90	Iodine	24

The meaning of these numbers is, in the case of water, for instance that it requires as much heat to convert a pound of water from the state of liquid at the boiling point to that of vapour at the same temperature, as would raise a pound of water through 540 degrees, or 540 pounds of water through one degree; or that the conversion of one pound of vapour of alcohol at 78° into liquid alcohol of the same temperature would heat 208 pounds of water through *one* degree.

Watt, who investigated the subject, found that *the whole quantity of heat necessary to raise a given weight of water from zero at any temperature, and then to evaporate it entirely, is a constant quantity.* His experiments showed that this quantity is 640. Hence the lower the temperature the greater the latent heat, and, on the other hand, the higher the temperature the less the latent heat. The latent heat of the vapour of water evaporated at 100° would be 540, while at 50° it would be 590. At higher temperatures the latent heat of aqueous vapour would go on diminishing. Water evaporated under a pressure of 15 atmospheres at a temperature of 200°, would have a latent heat of 440, and if it could be evaporated at 640° it would have no latent heat at all.

Experiments by Southern and Creighton in 1803 led to a different conclusion : namely, that *the latent heat of evaporation is a constant quantity for all temperatures, and that the total quantity of heat necessary to evaporate water is the sensible heat plus this constant,* which they found in round numbers to be 540; consequently, to evaporate water at 100°, 640 thermal units (413) would be needed, while it would require 200 + 540 = 740 thermal units to evaporate it at 200°.

Regnault, who examined this question with great care, arrived at results ich differed from both these laws. He found that the *total quantity of t necessary for the evaporation of water increases with the temperature,* l is not constant, as Watt had supposed. It is represented by the mula

$$Q = 606{\cdot}5 + 0{\cdot}305\ T,$$

which Q is the total quantity of heat, and T the temperature of the ter during evaporation, while the numbers are constant quantities. The al quantity of heat necessary to evaporate water at 100° is 606·5 + 305 × 100) = 637; at 120° it is 643; at 150° it is 651; and at 180° it is 1.

Thus the heat required to raise a pound of water from zero and convert into steam at 100° represents a mechanical work of 855430 units.

345. **Cold due to evaporation. Mercury frozen.**—Whatever be the mperature at which a vapour is produced, an absorption of heat always kes place. If, therefore, a liquid evaporates, and does not receive from thout a quantity of heat equal to that which is expended in producing e vapour, its temperature sinks, and the cooling is greater in proportion the evaporation is more rapid.

Leslie succeeded in freezing water by means of rapid evaporation. nder the receiver of the air pump is placed a vessel containing strong lphuric acid, and above it a thin metallic capsule (fig. 267) containing a

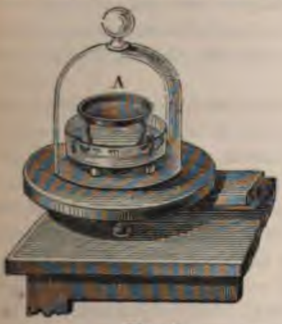


Fig. 267.

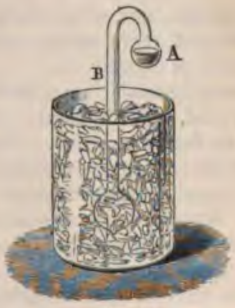


Fig. 268.

nall quantity of water. By exhausting the receiver the water begins to oil (339), and since the vapours are absorbed by the sulphuric acid as st as they are formed, a rapid evaporation is produced, which quickly fects the freezing of the water.

This experiment is best performed by using, instead of the thin metallic ssel, a watch-glass, coated with lampblack and resting on a cork. The vantage of this is twofold: firstly, the lampblack is a very bad nductor, and, secondly, it is not moistened by the liquid, which remains the form of a globule not in contact with the glass. A small porous h may advantageously be used.

The same result is obtained by means of Wollaston's *cryophorus* (fig.), which consists of a bent glass tube provided with a bulb at each end.

The apparatus is prepared by introducing a small quantity of water, wh
is then boiled so as to expel all air. It is then hermetically sealed, so
on cooling it contains only water and the vapour of water.

The water being introduced into the bulb A, the other is immersed
a freezing mixture. The vapours in the tube are thus condensed;
water in A rapidly yields more. But this rapid production of vapour re
quires a large amount of heat, which is abstracted from the water in
and its temperature is so much reduced that it freezes.

Carré has constructed an apparatus which is based upon Leslie's e
periment, and by which considerable quantities of water may be fro
in a very short time. It consists of a horizontal brass cylinder, ab
fifteen inches in length and four in diameter, lined on the inside with
alloy of antimony and lead, so as to resist the action of strong sulph
acid, with which it is about half filled. In the top of the cylinder, an
at one end, is fitted a brass tube, bent twice at right angles, and c
structed in such a manner that a flask containing water can be eas
fitted on air-tight. At the other end of the cylinder, also at the top, the
is a somewhat wide upright tube B. This is connected with a simple
pump, specially devised for the purpose, and there is an arrangement
that the motion which works the pump works also a stirrer, which keeps
the acid in continual agitation. A fresh surface is thus continually absorbing
aqueous vapour; and as the space to be exhausted is small, and
the pump very effective, soon after its working commences the water first
boils and then freezes. These apparatus have been introduced for industrial
purposes; and where there is a continual demand and use for dilute
sulphuric acid, there seems no reason why this should not be an economical
mode of making ice.

By using liquids more volatile than water, more particularly liquid sulphurous
acid, which boils at −10°, a degree of cold is obtained sufficiently
intense to freeze mercury. The experiment may be made by covering
the bulb of a thermometer with cotton wool, and after having moistened
it with liquid sulphurous acid, placing it under the receiver of the ai
pump. When a vacuum is produced the mercury is quickly frozen.

Thilorier, by directing a jet of liquid carbonic acid on the bulb of a
alcohol thermometer, obtained a cold of −100° without freezing the alco
hol. We have already seen, however (317), that with a mixture of soli
carbonic acid, liquid protoxide of nitrogen and ether, M. Despret
obtained a sufficient degree of cold to reduce alcohol to the viscou
state.

By means of the evaporation of bisulphide of carbon the formation o
ice may be illustrated without the aid of an air pump. A little water i
dropped on a small piece of wood, and a capsule of thin copper foil, con
taining bisulphide of carbon, is placed on the water. The evaporation o
the bisulphide is accelerated by means of a pair of bellows, and after
few minutes the water freezes round the capsule, so that the latter adhere
to the wood.

In like manner, if some water be placed in a test tube which is the
dipped in a glass containing some ether, and a current of air be blow

through the ether by means of a glass tube fitted to the nozzle of a pair of bellows, the rapid evaporation of the ether very soon freezes the water in the tube.

Richardson's apparatus for producing local anæsthesia also depends on the cold produced by the evaporation of ether.

The cold produced by evaporation is used in hot climates to cool water by means of *alcarrazas*. These are porous earthen vessels, through which water percolates, so that on the outside there is a continual evaporation which is accelerated when the vessels are placed in a current of air. For the same reason wine is cooled by wrapping the bottles in wet cloths and placing them in a draught.

In Harrison's method of making ice artificially, a steam engine is used to work an air pump, which produces a rapid evaporation of some ether, in which is immersed the vessel containing the water to be frozen. The apparatus is so constructed that the vaporised ether can be condensed and used again.

The cooling effect produced by a wind or draught does not necessarily arise from the wind being cooler, for it may, as shown by the thermometer, be actually warmer; but arises from the rapid evaporation it causes from the surface of the skin. We have the feeling of oppression, even at moderate temperatures, when we are in an atmosphere saturated by moisture in which no evaporation takes place.

346. **Carré's apparatus for freezing water.**—We have already seen hat when any liquid is converted into vapour it absorbs a considerable uantity of sensible heat; this furnishes a source of cold which is the nore abundant the more volatile the liquid and the greater its heat of aporisation.

This property of liquids has been utilised by M. Carré, in freezing vater by the distillation of ammonia. The apparatus consists of a cylinrical boiler C (figs. 269, 270) and of a slightly conical vessel A, which is he *freezer*. These two vessels are connected by a tube *m*, and a brace *n* inds them firmly. They are made of strong galvanised iron plate, and an resist a pressure of seven atmospheres.

The boiler C, which holds about two gallons, is three parts filled with a trong solution of ammonia. In a tubulure in the upper part of the boiler me oil is placed, and in this a thermometer *t* indicating temperatures om 100° to 150°. The freezer A consists of two concentric envelopes, such a manner that its centre being hollow, a metal vessel G, conining the water to be frozen, can be placed in this space. Hence only e annular space between the sides of the freezer is in communication ith the boiler by means of the tube *m*. In the upper part of the freezer ere is a small tubulure, which can be closed by a metal stopper, and by hich the solution of ammonia is introduced.

The formation of ice comprehends two distinct operations. In the st, the boiler is placed in a furnace F, and the freezer in a bath of cold ter of about 12°. The boiler being heated to 130° the ammoniacal s dissolved in the water of the boiler is disengaged, and, in virtue of own pressure, is liquefied in the freezer, along with about a tenth of its weight of water. This distillation of C towards A lasts about an hour and a quarter, and when it is finished the second operation commences; this consists in placing the boiler in the cold-water bath (fig. 270), and the

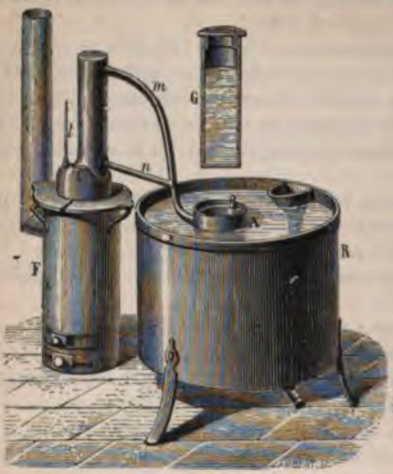


Fig. 269.

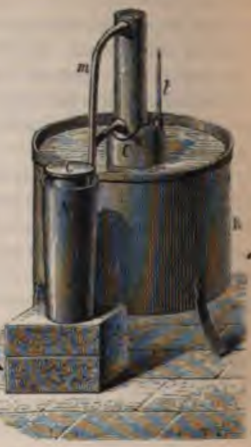


Fig. 270.

freezer outside, care being taken to surround it with very dry flannel. The vessel G, about three-quarters full of water, is placed in the freezer. As the boiler cools, the ammoniacal gas with which it is filled is again dissolved; the pressure thus being diminished the ammonia which has been liquefied in it is converted into the gaseous form, and now *distils* from A towards C, to redissolve in the water which has remained in the boiler. During this distillation the ammonia which is rarefied absorbs a great quantity of heat, which is withdrawn from the vessel G and the water it contains. Hence it is that this water freezes. In order to have better contact between the sides of the vessel G and the freezer, alcohol is poured between them. In about an hour and a quarter a perfectly compact cylindrical block of ice can be taken from the vessel G.

This apparatus gives about four pounds of ice in an hour, at a price of about a farthing per pound: large continuously working apparatus have, however, been constructed, which produce as much as 800 pounds of ice in an hour.

LIQUEFACTION OF VAPOURS AND GASES.

347. **Liquefaction of vapours.**—The *liquefaction* or *condensation* of vapours is their passage from the aëriform to the liquid state. Condensation may be due to three causes—cooling, compression, or chemical affinity. For the first two causes the vapours must be saturated (327), while the latter produces the liquefaction of the most rarefied vapours.

Thus, a large number of salts absorb and condense the aqueous vapour in the atmosphere, however small its quantity.

When vapours are condensed, their latent heat becomes free, that is, it affects the thermometer. This is readily seen when a current of steam

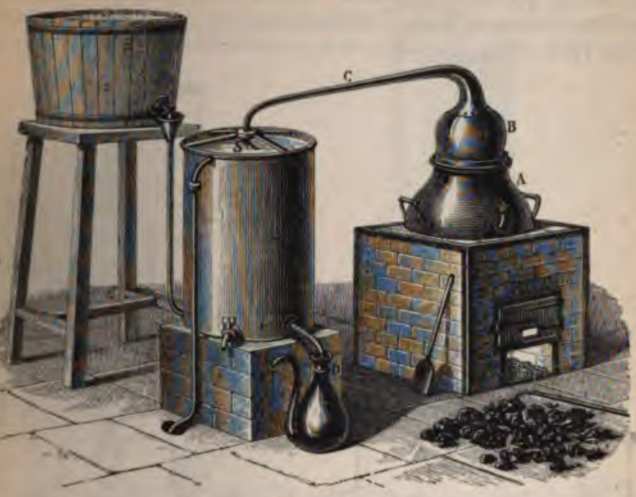


Fig. 271.

at 100° is passed into a vessel of water at the ordinary temperature. The liquid becomes rapidly heated, and soon reaches 100°. The quantity of heat given up in liquefaction is equal to the quantity absorbed in producing the vapour.

348. **Distillation. Stills.**—*Distillation* is an operation by which a volatile liquid may be separated from substances which it holds in solution, or by which two liquids of different volatilities may be separated. The operation depends on the transformation of liquids into vapours by the action of heat, and on the condensation of these vapours by cooling.

The apparatus used in distillation is called a *still*. Its form may vary reatly, but consists essentially of three parts : 1st, the *body*, A (fig. 271), copper vessel containing the liquid, the lower part of which fits in the urnace : 2nd, the *head*, B, which fits on the body, and from which a ateral tube, C, leads to, 3rd, *worm*, S, a long spiral tin or copper tube, laced in a cistern kept constantly full of cold water. The object of the orm is to condense the vapour, by exposing a greater extent of cold rface.

To free ordinary well water from the many impurities which it contains, is placed in a still and heated. The vapours disengaged are condensed the worm, and the distilled water arising from the condensation is col- cted in the receiver, D. The vapours in condensing rapidly heat the ater in the cistern, which must, therefore, be constantly renewed. For this purpose a continual supply of cold water passes into the bottom of the cistern, while the lighter heated water rises to the surface and escapes by a tube in the top of the cistern.

349. **Liebig's condenser.**—In distilling smaller quantities of liquids, or in taking the boiling point of a liquid, so as not to lose any of it, the apparatus known as *Liebig's condenser* is extremely useful. It consists of a glass tube, *tt*, fig. 272, about thirty inches long, fitted in a copper or tin

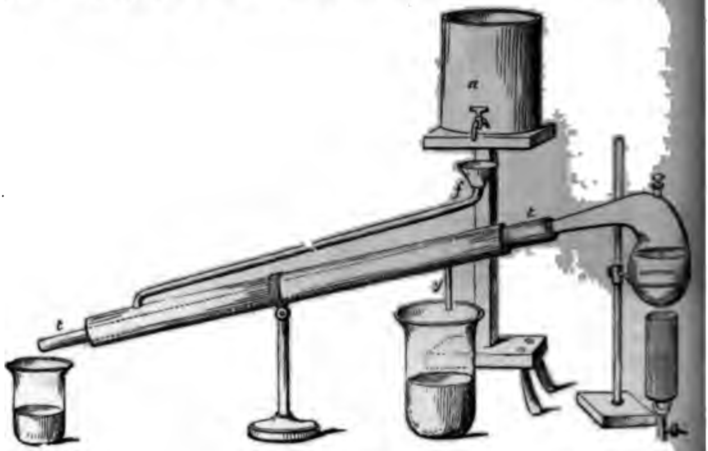


Fig. 272.

tube by means of perforated corks. A constant supply of cold water from the vessel *a* passes into the space between the two tubes, being conveyed to the lower part of the condenser by a funnel and tube *f*, and flowing out from the upper part of the tube *g*. The liquid to be distilled is contained in a retort, the neck of which is placed in the tube; the condensed liquid drops quite cold into a vessel placed to receive it at the other extremity of the condensing tube.

350. **Apparatus for determining the alcoholic value of wines.**—One of the forms of this apparatus consists of a glass flask resting on a tripod, and heated by a spirit lamp (fig. 273). By means of a caoutchouc tube this is connected with a serpentine placed in a copper vessel filled with cold water, and below which is a test-glass for collecting the distillate. On this are three divisions, one *a*, which measures the quantity of wine taken; the two others indicating one-half and one-third of this volume.

The test-glass is filled with the wine up to *a*, this is then poured into the flask, which, having been connected with the serpentine, the distillation is commenced. The liquid which distils over is a mixture of al and water; for ordinary wines, such as clarets and hocks, about one- is distilled over, and for wines richer in spirit, such as sherries and one-half must be distilled; experiment has shown that under these tances all the alcohol passes over in the distillate. The measure is filled up with distilled water to *a*; this gives a mixture of alcohol water of the same volume as the wine taken, free from all solid mat- such as sugar, colouring matter, and acid, but containing all the

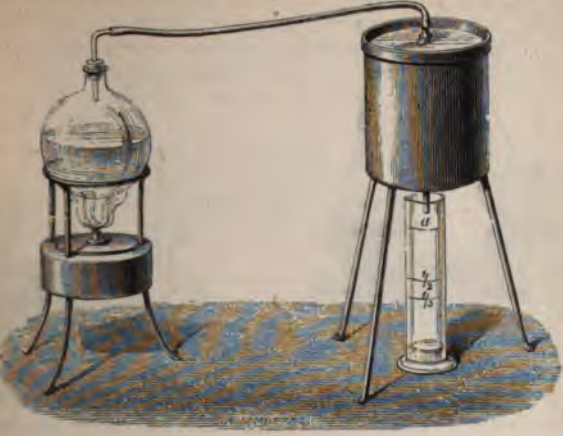


Fig. 273.

ohol. The specific gravity of this distillate is then taken by means of alcoholometer (123), and the number thus obtained corresponds to a tain strength of alcohol as indicated by the tables.

51. **Safety tube.**—In preparing gases and collecting them over mer- or water, it occasionally happens that these liquids rush back into generating vessel, and destroy the operation. This arises from an ss of atmospheric pressure over the tension in the vessel. If a gas, hurous acid, for example, be generated in the flask *m* (fig. 274), and ed into water in the vessel A, as long as gas is given off freely, its extension ex- s the atmospheric pressure and the ht of the column of water, *on*, so that the r in the vessel cannot rise in the tube, absorption is impossible. But if the ten- decreases either through the flask be- ng cooled, or the gas being disengaged slowly, the external pressure prevails, when it exceeds the internal tension by than the weight of the column of water ne water rises into the flask and the ation is spoiled. This accident is prevented by means of *safety*

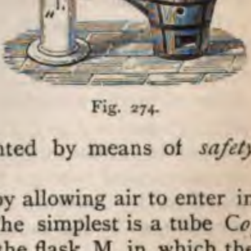


Fig. 274.

ese are tubes which prevent absorption by allowing air to enter in ortion as the internal tension decreases. The simplest is a tube C*o*, 75, passing through the cork which closes the flask M, in which the gas is generated and dipping in the liquid. When the tension of the gas diminishes in M, the atmospheric pressure on the water in the bath E, causes it to rise to a certain height in the tube DA; but this pressure, acting also on the liquid in the tube C*o*, depresses it to the same extent,

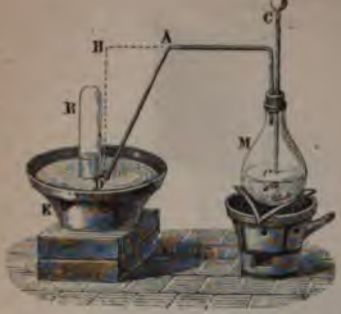


Fig. 275.

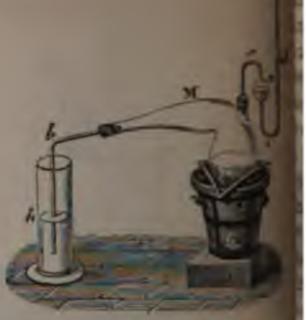


Fig. 276.

assuming that this liquid has the same density as the water in E. Now as the distance *or* is less than the height DH, air enters by the aperture *o*, before the water in the bath can rise to A, and no absorption takes place.

Fig. 276 represents another kind of safety tube. It has a bulb *a*, containing a certain quantity of liquid, as does also *id*. When the tension of the gas in the retort M exceeds the atmospheric pressure, the level in the leg *id* rises higher than in the bulb, *a*; if the gas has the tension of one atmosphere, the level is the same in the tube as in the bulb. Lastly, if the tension of the gas is less than the atmospheric pressure, the level sinks in the leg *di*; and, as care is taken that the height *ia* is less than *bh*, as soon as the air which enters through *c* reaches the curved part *i*, it raises the column *ia*, and passes into the retort before the water in the cylinder can reach *b*; the tension in the interior is then equal to the exterior pressure, and no absorption takes place.

352. **Liquefaction of gases.**—We have already seen that a saturated vapour, the temperature of which is constant, is liquefied by increasing the pressure, and that, the pressure remaining constant, it is brought into the liquid state by diminishing the temperature.

Unsaturated vapours behave in all respects like gases. And it is natural to suppose that what are ordinarily called *permanent gases* are really unsaturated vapours. For the gaseous form is accidental, and is not inherent in the nature of the substance. At ordinary temperatures sulphurous acid is a gas, while in countries near the poles it is a liquid; in temperate climates ether is a liquid, at a tropical heat it is a gas. And just as unsaturated vapours may be brought to the state of saturation and then liquefied by suitably diminishing the temperature or increasing the pressure, so by the same means gases may be liquefied. But as they are mostly very far removed from this state of saturation, great cold and pressure are required. Some of them may indeed be liquefied either by cold or by pressure; for the majority, however, both agencies must be simultaneously employed. Few gases can resist these combined actions, and probably those which have not yet been liquefied, hydrogen, oxygen, nitrogen, binoxide of nitrogen, and carbonic oxide, would become so if submitted to a sufficient degree of cold and pressure.

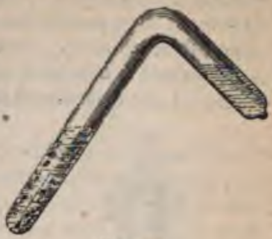


Fig. 277.

Faraday was the first to liquefy some of the gases. His method consists in enclosing in a bent glass tube (fig. 277) substances by whose chemical action the gas to be liquefied is produced and then sealing the shorter leg. In proportion as the gas is disengaged its pressure increases, and it ultimately liquefies and collects in the shorter leg, more especially if its condensation is assisted by placing the shorter leg in a freezing mixture. A mall manometer may be placed in the apparatus to indicate the pressure.

Cyanogen gas is readily liquefied by heating cyanide of mercury in a ent tube of this description; and carbonic acid by heating bicarbonate f soda; other gases have been condensed by taking advantage of special reactions, the consideration of which belongs rather to chemistry than to physics. For example, chloride of silver absorbs about 200 times its volume of ammoniacal gas; when the compound thus formed is placed in freezing tube and gently heated, while the shorter leg is immersed in a freezing mixture, a quantity of liquid ammoniacal gas speedily collects in he shorter leg.

353. **Apparatus to liquefy and solidify gases.**—Thilorier first constructed an apparatus by which considerable quantities of carbonic acid could be liquefied. Its principle is the same as that used by Faraday in working with glass tubes; the gas is generated in an iron cylinder, and passes through a metallic tube into another similar cylinder where it condenses. The use of this apparatus is not free from danger; many accidents have already happened with it, and it has been superseded by an apparatus constructed by Natterer, of Vienna, which is both convenient and safe.

A perspective view of the apparatus, as modified by M. Bianchi, is reprеented in fig. 279, and a section on a larger scale in fig. 278. It consists of wrought-iron reservoir A, of something less than a quart capacity, which an resist a pressure of more than 600 atmospheres. A small force pump screwed on the lower part of this reservoir. The piston rod *t* is moved y the crank rod E, which is worked by the handle M. As the compression of the gas and the friction of the piston produce a considerable isengagement of heat, the reservoir A is surrounded by a copper vessel, which ice or a freezing mixture is placed. The water arising from the elting of the ice passes by a tube, *m*, into a cylindrical copper case C, hich surrounds the force pump, from whence it escapes through the tube *n*, and the stopcock *o*. The whole arrangement rests on an ir frame, PQ.

The gas to be liquefied is previously collected in air-tight bags, R, fro whence it passes into a bottle, V, containing some suitable drying su stance ; it then passes into the condensing pump through the vulcanis india-rubber tube H. After the apparatus has been worked for some tin the reservoir A can be unscrewed from the pump without any escape the liquid, for it is closed below by a valve S (fig. 278). In order to colle

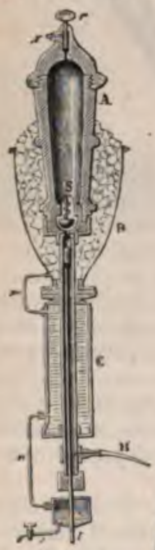


Fig. 278.

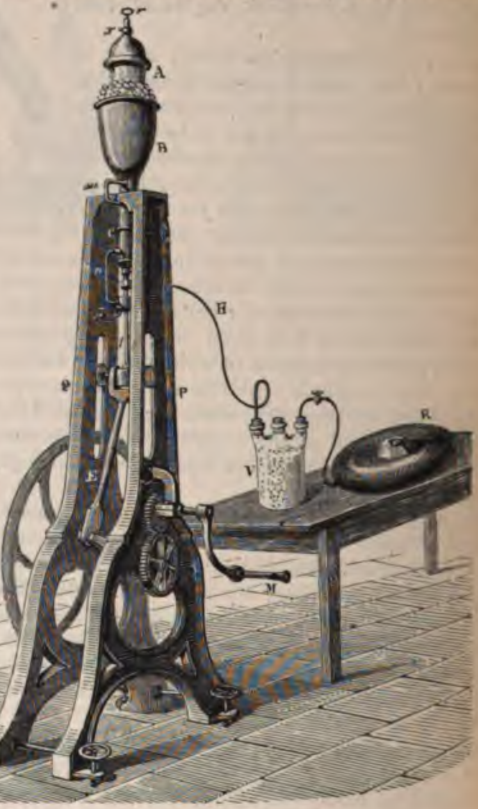


Fig. 279.

some of the liquid gas the reservoir is inverted and on turning the sto cock *r*, the liquid escapes by a small tubulure *x*.

When carbonic acid has been liquefied, and is allowed to escape int the air, a portion only of the liquid volatilises, in consequence of the hea absorbed by this evaporation ; the rest is so much cooled as to solidify white flakes like snow or anhydrous phosphoric acid.

Solid carbonic acid evaporates very slowly. By means of an alcoh hermometer its temperature has been found to be about −90°. A small antity placed on the hand does not produce the sensation of such great old as might be expected. This arises from the imperfect contact. But the solid be mixed with ether the cold produced is so intense that when little is placed on the skin all the effects of a severe burn are produced. mixture of these two substances solidifies four times its weight of merury in a few minutes. When a tube containing liquid carbonic acid is laced in this mixture, the liquid becomes solid, and looks like a transarent piece of ice.

The most remarkable liquefaction obtained by this apparatus is that of otoxide of nitrogen. The gas once liquefied only evaporates slowly, and oduces a temperature of 88° below zero. Mercury placed in it in small antities instantly solidifies. The same is the case with water; it must added drop by drop, otherwise its latent heat being much greater than at of mercury, the heat given up by the water in solidifying would be fficient to cause an explosion of the protoxide of nitrogen.

Protoxide of nitrogen is readily decomposed by heat, and has the prorty of supporting the combustion of bodies with almost as much brilncy as oxygen; and even at low temperatures it preserves this prorty. When a piece of incandescent charcoal is thrown on liquid proxide of nitrogen it continues to burn with a brilliant light.

The cold produced by the evaporation of ether has been used by MM. ir and Drion in the liquefaction of gases. By passing a current of air om a blowpipe bellows through several tubes into a few ounces of ether, temperature of −34° C. can be reached in five or six minutes, and may kept up for fifteen or twenty minutes. By evaporating liquid sulphuus acid in the same manner a greater degree of cold, −50° C., is obtained. t this temperature ammoniacal gas may be liquefied. By rapidly aporating liquid ammonia under the air pump, in the presence of lphuric acid, a temperature of −87° is attained, which is found sufficent to liquefy carbonic acid under the ordinary pressure of the atmohere.

By means of a bath of ether and of solid carbonic acid, and by using very gh pressures, Andrews succeeded in reducing air to $\frac{1}{675}$ of its bulk, ygen to $\frac{1}{554}$, hydrogen to $\frac{1}{500}$, carbonic oxide to $\frac{1}{278}$, and nitric oxide to of its original volume, but without producing liquefaction. Hydrogen d carbonic oxide departed less from Boyle's law than oxygen and tric oxide.

MIXTURES OF GASES AND VAPOURS.

354. **Laws of the mixture of gases and vapours.**—Every mixture of gas and a vapour obeys the following two laws:—

I. *The tension, and, consequently, the quantity of vapour which saturtes a given space, are the same for the same temperature, whether this ace contains a gas or is a vacuum.*

II. *The tension of the mixture of a gas and a vapour is equal to the m of the tensions which each would possess if it occupied the same space ne.*

These are known as *Dalton's laws*, from their discoverer, and a monstrated by the following apparatus, which was invented by Lussac :—It consists of a glass tube A (fig. 280), to which two stop *b* and *d*, are cemented. The lower stopcock is provided with a tul which connects the tube A with a tube B of smaller diameter. A between the two tubes serves to measure the heights of the me columns in these tubes.

The tube A is filled with mercury, and the stopcocks *b* and closed. A glass globe, M, filled with dry air or any other gas is sc on by means of a stopcock in the place of the funnel C. All three cocks are then opened, and a little mercury is allowed to escape, is replaced by the dry air of the globe. The stopcocks are then c and as the air in the tube expands on leaving the globe the pressur is less than that of the atmosphere. Mercury is accordingly poure the tube B until it is at the same level in both tubes. The globe i removed, and replaced by a funnel C, provided with a stopcock peculiar construction. It is not perforated, but has a small cavity, presented in *n*, on the left of the Some of the liquid to be vaporised is into C, and the height of the merc having been noted, the stopcock *b* is o and *a* turned, so that its cavity become with liquid; being again turned, the enters the space A and vaporises. liquid is allowed to fall drop by dro the air in the tube is saturated, which case when the level *k* of the mercury to sink (326).

As the tension of the vapour prod the space A is added to that of t already present, the total volume of increased. It may easily be restored original volume by pouring mercury When the mercury in the large tube ha raised to the level *k*, there is a diff B*o*, in the level of the mercury in t tubes, which obviously represents the t of the vapour; for as the air has resu original volume, its tension has not ch Now if a few drops of the same liq passed into the vacuum of a barometr a depression exactly equal to B*o* is pro which proves that, for the same tempe the tension of a saturated vapour is th in a gas as in a vacuum; from whic concluded that at the same temperat quantity of vapour is also the same.

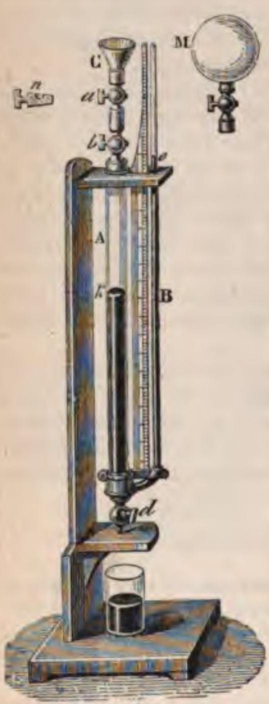


Fig. 280.

The second law is likewise proved by this experiment, for wh cury has regained its level, the mixture supports the atmospheric sure on the top of the column B, in addition to the weight of the mn of mercury B*o*. But of these two pressures, one represents the ion of the dry air, and the other the tension of the vapour. The nd law is, moreover, a necessary consequence of the first.

xperiments can only be made with this apparatus at ordinary tematures : but M. Regnault, by means of an apparatus which can be d at different temperatures, has investigated the tensions of the ours of water, ether, bisulphide of carbon, and benzole, both *in vacuo* l in air. He has found that the tension in air is less than it is *in uo*, but the differences are so small as not to invalidate Dalton's law. Regnault is even inclined to consider this law as theoretically true, ibuting the differences which he observed to the hygroscopic properties of the sides of the tube.

55. **Problems on mixtures of gases and vapours.**—I. A volume of air V, at the pressure H, being given, what will be its volume V′, en it is saturated with vapour, the temperature and the pressure reining the same?

f F be the elastic force of the vapour which saturates the air, the ter, in the mixture, only supports a pressure equal to H – F (354). But Boyle and Mariotte's law the volumes V and V′ are inversely as their ssures, consequently

$$\frac{V'}{V} = \frac{H}{H-F}, \text{ whence } V' = \frac{VH}{H-F}.$$

II. Let V be a given volume of saturated air at the pressure H, and the mperature *t*, what will be its volume V′, also saturated, at the pressure ′, and the temperature *t*′?

If *f* be the maximum tension of aqueous vapour at *t*°, and *f*′ its maxim tension at *t*′°, the air alone in each of the mixtures V and V′ will be spectively under the pressures H – *f* and H′ – *f*′ ; consequently, assumg first that the temperature is constant, we obtain

$$\frac{V'}{V} \; \frac{H-f}{H'-f'}$$

t as the volumes V′ and V of air, at the temperatures *t*′ and *t*, are in e ratio of 1 + *αt*′ to 1 + *αt*, *a* being the coefficient of the expansion of air, e equation becomes

$$\frac{V'}{V} = \frac{H-f}{H' \times f'} \times \frac{1+\alpha t'}{1+\alpha t}.$$

III. What is the weight P of a volume of air V, saturated with aqueous pour at the temperature *t*, and pressure H?

If we call F the maximum tension of the vapour at *t*°, the tension of e air alone will be H – F, and the problem reduces itself to finding : t, the weight of V cubic inches of dry air at *t*, and under the pressure – F ; and 2nd, the weight of V cubic inches of saturated vapour at *t*° der the pressure F.

To solve the first part of the problem, we know that a cubic inch of dry air at 0° and the pressure 760 millimeters weighs 0·31 grains, and that at $t°$, and the pressure H – F, it weighs $\frac{0{\cdot}31\,(H-F)}{(1+at)\,760}$ (306), consequently V cubic inches of dry air weigh

$$\frac{0{\cdot}31\,(H-F)\,V}{(1+at)\,760} \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;(1)$$

To obtain the weight of the vapour, the weight of the same volume of dry air at the same temperature and pressure must be sought, and this is to be multiplied by the relative density of the vapour. Now as V cubic inches of dry air at $t°$, and the pressure F, weigh $\frac{0{\cdot}31 \times VF}{(1+at)\,760}$ V cubic inches of aqueous vapour, whose density is $\frac{5}{8}$ of that of air (358), weigh

$$\frac{0{\cdot}31 \times VF}{(1+at)\,760} \times \frac{5}{8} \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;(2)$$

and as the weight P is equal to the sum of the weights (1) and (2) we have

$$P = \frac{0{\cdot}31 \times V\,(H-F}{(1+at)\,760} + \left[\frac{0{\cdot}31 \times VF}{(1+at)\,760} \times \frac{5}{8}\right] = \frac{0{\cdot}31 \times VF}{(1+at)\,760}(H - \tfrac{3}{8}F).$$

SPHEROIDAL CONDITION.

356. **Leidenfrost's phenomenon.—Boutigny's experiments.**—When liquids are thrown upon incandescent metallic surfaces they present remarkable phenomena, which were first observed by Leidenfrost a century ago, and have been named after their discoverer. They have since then been studied by other physicists, and more especially by M. Boutigny, to whom our present knowledge of the subject is mainly due.

When a tolerably thick silver or platinum dish is heated to redness, and a little water, previously warmed, dropped into the dish by means of a pipette, the liquid does not spread itself out on the dish, and does not moisten it, as it would at the ordinary temperature, but assumes the form of a flattened globule, which fact M. Boutigny expresses by saying that it has passed into the *spheroidal state*. It rotates rapidly round on the bottom of the dish, taking sometimes the form of a star, and not only does it not boil, but its evaporation is only about one fiftieth as rapid as if it boiled. As the dish cools, a point is reached at which it is not hot enough to keep the water in the spheroidal state; it is accordingly moistened by the liquid, and a violent ebullition suddenly ensues.

All volatile liquids can assume the spheroidal condition; the lowest temperature at which it can be produced varies with each liquid, and is more elevated the higher the boiling point of the liquid. For water, dish must have at least a temperature of 200°; for alcohol, 134°; and ether, 61°.

The temperature of a liquid in the spheroidal state is always below its boiling point. This temperature has been measured by M. Boutigny by means of a very delicate thermometer; but his method is not free from objections, and it is probable that the temperatures he obtained were too high. He found that of water to be 95°; alcohol, 75°; ether, 34°; and liquid sulphurous acid, −11°. But the temperature of the vapour which is disengaged appears to be as high as that of the vessel itself.

This property of liquids in the spheroidal state remaining below their boiling point has been applied by M. Boutigny in a remarkable experiment, that of freezing water in a red-hot crucible. He heated a platinum dish to bright redness, and placed a small quantity of liquid sulphurous acid in it. It immediately assumed the spheroidal condition, and its evaporation was remarkably slow. Its temperature, as has been stated, was about −11°, and when a small quantity of water was added it immediately solidified, and a small piece of ice could be thrown out of the red-hot crucible. In a similar manner Faraday, by means of a mixture of solid carbonic acid and ether, succeeded in freezing mercury in a red-hot crucible.

In the spheroidal state the liquid is not in contact with the vessel. M. Boutigny proved this by heating a silver plate placed in a horizontal position, and dropping on it a little dark-coloured water. The liquid assumed the spheroidal condition, and the flame of a candle placed at some distance could be distinctly seen between the drop and the plate. If a plate perforated by several fine holes be heated, a liquid will assume the spheroidal state when projected upon it. This is also the case with a flat helix of platinum wire pressed into a slightly concave shape. An experiment of another class, due to Mr. A. H. Church, also illustrates the same fact. A polished silver dish is made red-hot, and a few drops of a solution of sulphide of sodium are projected on it. The liquid passes into the spheroidal condition, and the silver undergoes no alteration. But if the dish is allowed to cool, the liquid instantly moistens it, producing a dark spot, due to the formation of sulphide of silver. In like manner nitric acid assumes the spheroidal state when projected on a heated silver plate, and does not attack the metal so long as the plate remains hot.

An analogous phenomenon is observed when potassium is placed on water. Hydrogen is liberated, and burns with a yellow flame; hydrate of potassium, which is formed at the same time, floats on the surface without touching it, owing to its high temperature. In a short time it cools down, and the globule coming in contact with water bursts with an explosion.

Similarly liquids may be made to roll upon liquids, and solid bodies which vaporise without becoming liquid also assume a condition analogous to the spheroidal state of liquids when they are placed on a surface whose temperature is sufficiently high to vaporise them rapidly. This is seen when a piece of carbonate of ammonium is placed in a red-hot platinum crucible.

The phenomena of the spheroidal state seem to prove that the liquid globule rests upon a sort of cushion of its own vapour, produced by the heat radiated from the hot surface against its under-side. As fast a this vapour escapes from under the globule, its place is supplied by fresh quantity formed in the same way, so that the globule is constantly buoyed up by it, and does not come in actual contact with the heated surface. When, however, the temperature of the latter falls, the formation of vapour at the under-surface becomes less and less rapid, until at length it is not sufficient to prevent the globule touching the hot metal or liquid on which it rests. As soon as contact occurs heat is rapidly imparted to the globule, it enters into ebullition, and quickly boils away.

These experiments on the spheroidal state explain the fact that the hand may be dipped into melted lead, or even melted iron, without injury. It is necessary that the liquid metal be heated greatly above its solidifying point. Usually the natural moisture of the hand is sufficient, but it is better to wipe it with a damp cloth. In consequence of the great heat the hand becomes covered with a layer of spheroidal fluid, which prevents the contact of the metal with the hand. Radiant heat alone operates, and this is principally expended in forming aqueous vapour on the surface of the hand. If the hand is immersed in boiling water, the water adheres to the flesh, and consequently a scald is produced.

The tales of ordeals by fire during the middle ages, of men who could run barefooted over red-hot iron without being injured, are possibly true in some cases, and would find a ready explanation in the preceding phenomena.

DENSITY OF VAPOURS.

357. **Gay-Lussac's method.**—The *density of a vapour* is the relation between the weight of a given volume of this vapour and of that of the same volume of air at the same temperature and pressure.

Two methods principally are used in determining the density of vapours : Gay-Lussac's, which serves for liquids that boil at about 100°, and Dumas', which can be used up to 350°.

Figure 281 represents the apparatus used by Gay-Lussac. It consists of an iron vessel containing mercury, in which there is a glass cylinder, M. This is filled with water or oil, and the temperature is indicated by the thermometer, T. In the interior of the cylinder is a graduated glass jar, C, which, at first, is filled with mercury.

The liquid whose vapour density is to be determined is placed in a small bulb, A, represented on the left of the figure. The bulb is then sealed and weighed; the weight of the liquid taken is obviously the weight of the bulb when filled, minus its weight while empty. The bulb is then introduced into the jar C, and the liquid in M gradually heated somewhat higher than the boiling point of the liquid in the bulb. In consequence of the expansion of this liquid the bulb breaks, and the liquid becoming converted into vapour the mercury is depressed, a represented in the figure. The bulb must be so small that all the liquid in it is vaporised. The volume of the vapour is given by the graduati

ir. Its temperature is indicated by the thermometer T, and the
is indicated by the difference between the height of the baro-
the time of the observation, and
it of the column of mercury in the
It is only necessary then to calcu-
weight of a volume of air equal to
e vapour under the same conditions
ature and pressure. The quotient,
by dividing the weight of the va-
that of the air, gives the required
f the vapour.

be the weight of the vapour in
its volume in cubic inches, and t
rature; if H be the height of the
r, and h that of the mercury in the
ie pressure on the vapour will be

quired to find the weight p' of a
f air v, at the temperature t, and
ressure $H-h$. At zero, under the
760 millimeters, a cubic inch of air
31 grain; consequently, under the
ditions, v cubic inches will weigh
ain. And therefore the weight of
iches of air, at $t°$ and the pressure
neters, is

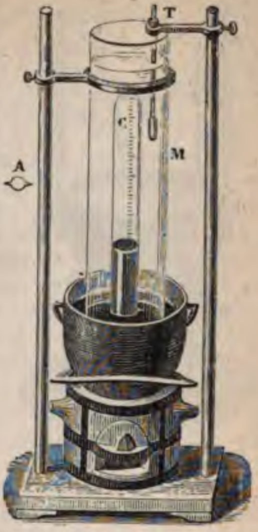


Fig. 281.

$$\frac{0{\cdot}31v}{1+\alpha t} \text{ grain [306, prob. ii.].}$$

weight of a volume of air is proportional to the pressure, the
ight may be reduced to the pressure $H-h$ by multiplying by
ich gives

$$\frac{0{\cdot}31\,v\,(H-h)}{(1+\alpha t)\,760}$$

eight p' of the volume of air v, at the pressure $H-h$, at $t°$.
ntly, for the desired density we have

$$D=\frac{p}{p'}=\frac{p\,(1+\alpha t)\,760}{0{\cdot}31\,v\,(H-h)}.$$

ımas' method.—The method just described cannot be applied
whose boiling point exceeds 150° or 160°. In order to raise
the cylinder to this temperature it would be necessary to heat
iry to such a degree that the mercurial vapours would be
to the operator. And, moreover, the tension of the mercurial
ı the graduated jar would increase the tension of the vapour of
, and so far vitiate the result.

owing method, devised by M. Dumas, can be used up to the temperature at which glass begins to soften; that is, about 400°. A glass globe is used with the neck drawn out to a fine point (fig. 282). The globe, having been dried externally and internally, is weighed, the temperature t and barometric height h being noted. This weight W is the weight of the glass G in addition to p, the weight of the air it contains. The globe is then gently warmed and its point immersed in the liquid whose vapour density is to be determined: on cooling, the air contracts, and a quantity of liquid enters the globe. The globe is then immersed in a bath, either of oil or fusible metal, according to the temperature to which it is to be raised. In order to keep the globe in a vertical position a metallic support, on which a movable rod slides, is fixed on the side of the vessel. This rod has two rings, between which the globe is placed, as shown in the figure. There is another rod, to which a weight thermometer, D, is attached.

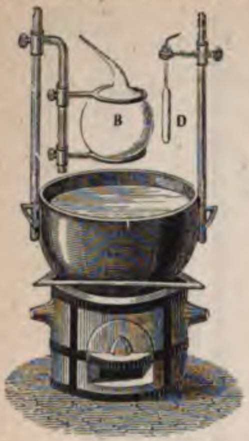


Fig. 282.

The globe and thermometer having been immersed in the bath, the latter is heated until slightly above the boiling point of the liquid in the globe. The vapour which passes out by the point expels all the air in the interior. When the jet of vapour ceases, which is the case when all the liquid has been converted into vapour, the point of the globe is hermetically sealed, the temperature of the bath t', and the barometric height h', being noted. When the globe is cooled, it is carefully cleaned and again weighed. This weight, W′, is that of the glass, G, plus p', the weight of the vapour which fills the globe at the temperature t' and pressure h', or $W' = G + p$. To obtain the weight of the glass alone, the weight p of air must be known, which is determined in the following manner: The point of the globe is placed under mercury and the extremity broken off with a small pair of pinchers: the vapour being condensed, a vacuum is produced, and mercury rushes up, completely filling the globe, if, in the experiment, all the air has been completely expelled. The mercury is then poured into a carefully graduated measure, which gives the volume of the globe. From this result, the volume of the globe at the temperature t' may be easily calculated and consequently the volume of the vapour. From this determination of the volume of the globe the weight p of the air at the temperature t and pressure h is readily calculated, and this result subtracted from W gives G, the weight of the glass. Now the weight of the vapour p' is $W' - G$. We now know the weight p' of a given volume of vapour at the temperature t' and pressure h', and it is only necessary to calculate the weight p'' of the same volume of air under the same conditions, which is easily accomplished. The quotient $\frac{p'}{p''}$ is the required density of the vapour.

Densities of Vapours.

Air	1·0000	Vapour of phosphorus .	4·3256
Vapour of water . .	0·6235	" turpentine .	5·0130
" alcohol . .	1·6138	" sulphur .	6·6542
" ether . .	2·5860	" mercury .	6·9760
" bisulphide of carbon	2·6447	" iodine .	8·7160

The density of aqueous vapour, when a space is saturated with it, is at all temperatures $\frac{5}{8}$, or, more accurately, 0·6225, of the density of air at the same temperature and pressure.

359. **Deville and Troost's method.**—Deville and Troost have modified Dumas' method so that it can be used for determining the vapour density of liquids with very high boiling points. The globe is heated in an iron cylinder in the vapour of mercury or of sulphur, the temperatures of which are constant respectively at 350° and 460°. In other respects the determination is the same as in Dumas' method.

For determinations at higher temperatures, Deville and Troost have employed the vapour of zinc, the temperature of which is 1040°. As glass vessels are softened by this heat, they use porcelain globes with finely drawn out necks, which are sealed by means of the oxyhydrogen flame.

360. **Relation between the volume of a liquid and that of its vapour.**—The density of vapour being known, we can readily calculate the ratio between the volume of a vapour in the saturated state at a given temperature, and that of its liquid at zero. We may take, as an example, the relation between water at zero and steam at 100°.

The ratio between the weights of equal volumes of air at zero, and the normal barometric pressure, and of water under the same circumstance is as 1 : 773. But from what has been already said (306), the density of air at zero is to its density at 100° as $1+\alpha t : 1$. Hence the ratio between the weights of equal volumes of air at 100° and water at 0°, is

$\frac{1}{1+0{\cdot}003665 \times 100} : 773$, or 0·73178 : 773.

Now from the above table the density of steam at 100° C., and the normal pressure, compared with that of air under the same circumstances, is as 0·6225 : 1. Hence the ratio between the weights of equal volumes of steam at 100°, and water at 0°, is

$$0{\cdot}73178 \times 0{\cdot}6225 : 773, \text{ or } 0{\cdot}4555 : 773 \text{ or } 1 : 1698.$$

Therefore, as the volumes of bodies are inversely as their densities, one volume of water at zero expands into 1698 volumes of steam at 100° C. The practical rule that a cubic inch of water yields a cubic foot of steam, though not quite accurate, expresses the relation in a convenient form.

CHAPTER VI.

HYGROMETRY.

361. **Object of hygrometry.**—The object of *hygrometry* is to determine the quantity of aqueous vapour contained in a given volume of air. This quantity is very variable; but the atmosphere is never completely saturated with vapour, at any rate, in our climates. Nor is it ever completely dry; for if *hygrometric substances*, that is to say, substances with a great affinity for water, such as chloride of calcium, sulphuric acid, etc., be at any time exposed to the air, they absorb aqueous vapour.

362. **Hygrometric state.**—As in general the air is never saturated, the ratio of the quantity of aqueous vapour actually present in the atmosphere, to that which it would contain if it were saturated, the temperature remaining the same, is called the *hygrometric state*, or *degree of saturation*.

The degree of moisture does not depend on the absolute quantity of aqueous vapour present in the air, but on the greater or less distance of the air from its point of saturation. When the air is cold it may be moist with very little vapour, and, on the contrary, when it is warm, very dry, even with a large quantity of vapour. In summer the air usually contains more aqueous vapour than in winter, notwithstanding which it is less moist, because, the temperature being higher, the vapour is farther from its point of saturation. When a room is warmed, the quantity of moisture is not diminished, but the humidity of the air is lessened, because its point of saturation is raised. The air may thus become so dry as to be injurious to the health, and it is hence usual to place vessels of water on the stoves used for heating.

As Boyle's law applies to nonsaturated vapours as well as to gases (326), it follows that, with the same temperature and volume, the weight of vapour in a nonsaturated space increases with the pressure and therefore with the tension of the vapour itself. Instead, therefore, of the ratio of the quantities of vapour, that of the corresponding tensions may be substituted, and it may be said that the hygrometric state is *the ratio of the tension of the aqueous vapour which the air actually contains, to the tension of the vapour which it would contain at the same temperature if it were saturated.*

If f is the actual tension of aqueous vapour in the air, and F that of saturated vapour at the same temperature, and E the hygrometric state, we have $E = \frac{f}{F}$; whence $f = F \times E$.

As a consequence of this second definition, it is important to notice that the temperature having varied, the air may contain the same quantity of vapour and yet not have the same hygrometric state. For when the temperature rises, the tension of the vapour which the ai would contain if saturated increases more rapidly than the tension o the vapour actually present in the atmosphere, and hence the rati ween the two forces, that is to say, the hygrometric state, becomes aller.

t will presently be explained (370) how the weight of the vapour tained in a given volume of air may be deduced from the hygrometric te.

63. **Different kinds of hygrometers.**—*Hygrometers* are instruments measuring the hygrometric state of the air. There are numerous ieties of them—chemical hygrometers, condensing hygrometers, and chrometers.

64. **Chemical hygrometer.**—The method of the chemical hygroter consists in passing a known volume of air over a substance which dily absorbs moisture—chloride of calcium, for instance. The subnce having been weighed before the passage of the air, and then afterrds, the increase in weight represents the amount of aqueous vapour sent in the air. By means of the apparatus represented in fig. 283, it

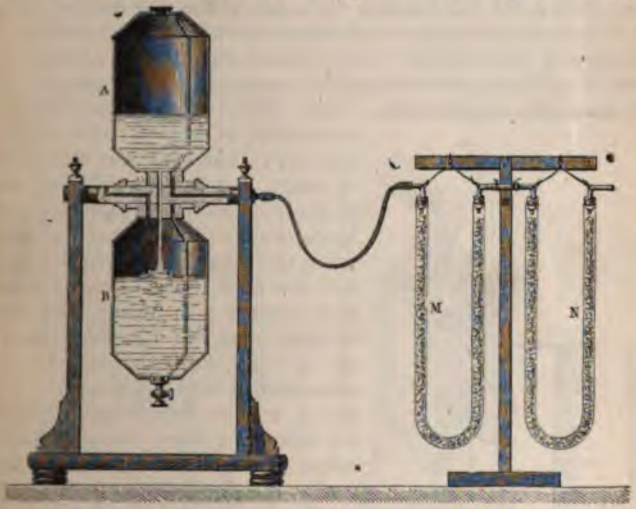


Fig. 283.

possible to examine any given volume. Two brass reservoirs A and B, the same size and construction, act alternately as aspirators, by being ed to the same axis, about which they can turn. They are connected a central tubulure, and by means of two tubulures in the axis the lower ervoir is always in connection with the atmosphere, while the upper e, by means of a caoutchouc tube, is connected with two tubes M and filled either with chloride of calcium, or with pumice stone imgnated with sulphuric acid. The first absorbs the vapour in the air wn through, while the other, M, stops any vapour which might diffuse m the reservoirs to the tube N.

The lower reservoir being full of water, and the upper one of air, the paratus is inverted so that the liquid flows slowly from A to B. A vacuum being formed in A, air enters by the tubes NM, in the first of which all the vapour is absorbed. When all the water has run into B it is turned; the same flow recommences, and the same volume of air is drawn through the tube N. Thus, if each reservoir holds a gallon, for example, and the apparatus has been turned five times, 6 gallons of air have traversed the tube N, and have been dried. If then, before the experiment, the tube with its contents has been weighed, the increase in weight gives the weight of aqueous vapour present in 6 gallons of air at the time of the experiment.

365. **Condensing hygrometers.**—When a body gradually cools in a moist atmosphere, as, for instance, when a lump of ice is placed in water contained in a polished metal vessel, the layer of air in immediate contact with it cools also, and a point is ultimately reached at which the vapour present is just sufficient to saturate the air: the least diminution of temperature then causes a precipitation of moisture on the vessel in the form of dew. When the temperature rises again, the dew disappears. The mean of these two temperatures is taken as the *dew point*, and the object of condensing hygrometers is to observe this point. Daniell's and Regnault's hygrometers belong to this class.

366. **Daniell's hygrometer.**—This consists of two glass bulbs at the extremities of a glass tube bent twice (fig. 284). The bulb A is two-thirds full of ether, and a very delicate thermometer plunges in it; the rest of the space contains nothing but the vapour of ether, the ether having been boiled before the bulb B was sealed. The bulb B is covered with muslin, and ether is dropped upon it. The ether in evaporating cools the bulb, and the vapour contained in it is condensed. The internal tension being thus diminished, the ether in A forms vapours which condense in the other bulb B. In proportion as the liquid distils from the lower to the upper bulb, the ether becomes cooler, and ultimately the temperature of the air in immediate contact with A sinks to that point at which its vapour is more than sufficient to saturate it, and it is, accordingly, deposited on the outside as a ring of dew corresponding to the surface of the ether. The temperature of this point is noted by means of the thermometer in the inside. The addition of ether to the bulb B is then discontinued, the temperature of A rises, and the temperature at which the dew disappears is noted. In order to render the deposition of dew more perceptible, the bulb A is made of black glass.

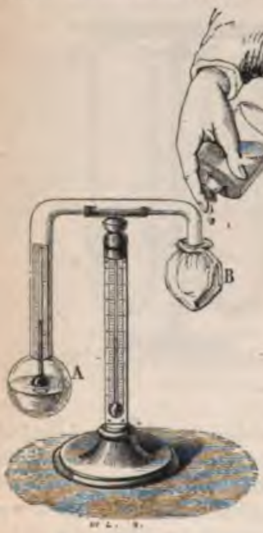


Fig. 284.

These two points having been determined, their mean is taken as that of r point. The temperature of the air at the time of the experiment is ed by the thermometer on the stem. The tension *f*, corresponding emperature of the dew point, is then found in the table of tensions This tension is exactly that of the vapour present in the air at e of the experiment. The tension F of vapour saturated at the ature of the atmosphere is found by means of the same table; the it obtained by dividing *f* by F, represents the hygrometric state of (362). For instance, the temperature of the air being 50°, sup- e dew point is 5°. From the table the corresponding tensions are 4 millimeters, and F = 12·699 millimeters, which gives 0·514 for the f *f* to F, or the hygrometric state.

e are many sources of error in Daniell's hygrometer. The al are: 1st, that as the evaporation in the bulb A only cools uid on the surface, the thermometer dipping on it does not give the dew point; 2nd, that the observer standing near the ient modifies the hygrometric state of the surrounding air, as its temperature; the cold ether vapour too flowing from the oulb may cause inaccuracy.

Regnault's hygrometer.—Regnault's hygrometer is free from

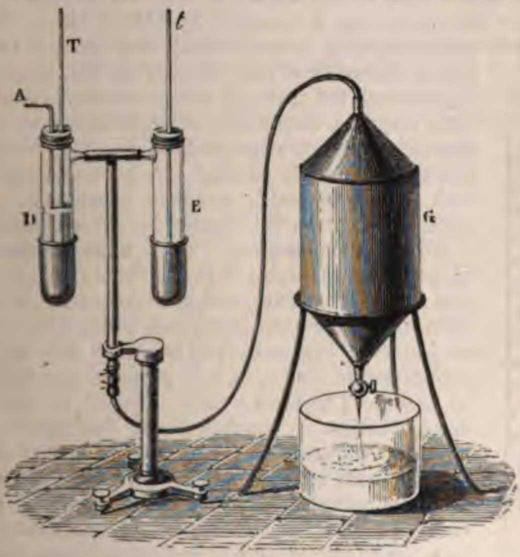


Fig. 285

irces of error incidental to the use of Daniell's. It consists of two in polished silver thimbles 1·75 inch in height, and 0·75 inch in er (fig. 285). In these are fixed two glass tubes, D and E, in each ch is a thermometer. A bent tube, A, open at both ends, passes h the cork of the tube D, and reaches nearly to the bottom of mble. There is a tubulure on the side of D, fitting in a brass tube which forms a support for the apparatus. The end of thi is connected with an aspirator G. The tube E is not connecte the aspirator; its thermometer simply indicates the temperature atmosphere.

The tube D is then half filled with ether, and the stopcock aspirator opened. The water contained in it runs out, and just as air enters through the tube A, bubbling through the ether, and c it to evaporate. This evaporation produces a diminution of tempe so that dew is deposited on the silver just as on the bulb in D hygrometer; the thermometer T is then instantly to be read, a stream from the aspirator stopped. The dew will soon disappear and the thermometer T is again to be read; the mean of th readings is taken: the thermometer t gives the corresponding temp of the air, and hence there are all the elements necessary for calc the hygrometric state.

As in this instrument, all the ether is at the same temperat consequence of the agitation, and the temperatures are read of distance by means of a telescope, the sources of error in Daniell's meter are avoided.

A much simpler form of the apparatus may be constructed o common test tube containing a depth of 1½ inch of ether. The provided with a loosely fitting cork in which is a delicate therm and a narrow bent tube dipping in the ether. Or ing through the ether, by a caoutchouc tube of co able length, a diminution of temperature is cause dew is ultimately deposited on the glass; after practice the whole process can be conducted aln well as in Regnault's complete instrument. Th perature of the air is indicated by a free thermome

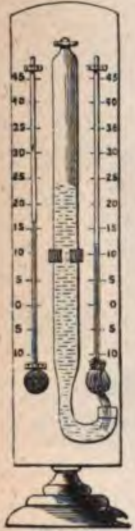


Fig. 286.

368. **Psychrometer. Wet bulb hygromet** moist body evaporates in the air more rapidly in p tion as the air is drier, and in consequence of this ration the temperature of the body sinks. The *psychr* or *wet bulb hygrometer*, is based on this princip application of which, to this purpose, was first sug by Leslie. The form usually adopted in this cou due to Mason. It consists of two delicate thermo placed on a wooden stand (fig. 286). One of the b covered with muslin, and is kept continually m being connected with a reservoir of water by mea string. Unless the air is saturated with moisture t bulb thermometer always indicates a lower temp than the other, and the difference between the indi of the two thermometers is greater in proportion as can take up more moisture. The tension e of the a vapour in the atmosphere may be calculated from the indications thermometer by means of the following empirical formula :—

$$e = e' - 0{\cdot}00077\,(t - t_1)h,$$

n which e' is the maximum tension corresponding to the temperature of e wet bulb thermometer, h is the barometric height, and t and t' the espective temperatures of the dry and wet bulb thermometers. If, for xample, $h = 750$ millimeters, $t = 15°$ C., $t' = 10°$C.; according to the table f tensions (331), $e' = 9{\cdot}165$, and we have

$$e = 9{\cdot}165 - 0{\cdot}00077 \times 5 \times 750 = 6{\cdot}278.$$

This tension corresponds to a dew point of about 4·5° C. If the air had een saturated, the tension would have been 12·699, and the air is thereore about half saturated with moisture.

This formula expresses the result with tolerable accuracy, but the bove constant 0·00077 requires to be controlled for different positions f the instrument; in small closed rooms it is 0·00128, in large rooms it is 00100, and in the open air without wind it is 0·00090: the number 0077 is its value in a large room with open windows. Regnault found t the difference in temperature of the two bulbs depends on the idity of the current of air; he also found that at a low temperature d in very moist air, the results obtained with the psychrometer differed n those yielded by his hygrometer. It is probable that the indications he psychrometer are only true for mean and high temperatures, and n the atmosphere is not too moist.

ccording to Glaisher the temperature of the dew point may be obtained multiplying the difference between the temperatures of the wet and bulb by a constant depending on the temperature of the air at the e of observation, and subtracting the product thus obtained from this named temperature. The following are the numbers :—

emperature F.° Dry Bulb	Factor	Dry Bulb Temperature F.°	Factor
Below 24°	8·5	34 to 35	2·8
24 to 25	6·9	35—40	2·5
25—26	6·5	40—45	2·2
26—27	6·1	45—50	2·1
27—28	5·6	50—55	2·0
28—29	5·1	55—60	1·9
29—30	4·6	60—65	1·8
30—31	4·1	65—70	1·8
31—32	3·7	70—75	1·7
32—33	3·3	75—80	1·7
33—34	3·0	80—85	1·6

se are often known as *Glaisher's factors.*

formula frequently used in this country is that given by Dr. Apjohn.

$$F = f - \frac{d}{88} \times \frac{h}{30}, \text{ or } F = f - \frac{d}{96} \times \frac{h}{30}$$

hich d is the difference of the wet and dry bulb thermometers in *enheit* degrees; h the barometric height in *inches*; f the tension of vapour for the temperature of the *wet bulb*, and F the elastic force vapour at the dew point, from which the dew point may if necessary found from the tables. The constant coefficient 88, for the specific hea of air and aqueous vapour, is to be used when the reading of the wet bu is above 32° F., and 96 when it is below.

369. **Hygrometers of absorption.**—These hygrometers are based o the property which organic substances have, of elongating when moist and of again contracting as they become dry. The most common form is the *hair* or *Saussure's hygrometer*.

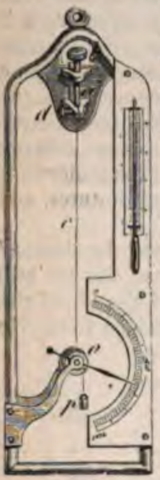


Fig. 287.

It consists of a brass frame (fig. 287), on which is fixed a hair, *c*, fas- tened at its upper extremity in a clamp, *a*, provided with a screw, This clamp is moved by a screw *b*. The lower part o the hair passes round a pulley, *o*, and supports a small weight, *p*. On the pulley there is a needle, which move along a graduated scale. When the hair becomes shorte the needle rises, when it becomes longer the weight makes it sink.

The scale is graduated by calling that point zero a which the needle would stand if the air were completel dry, and 100 the point at which it stands in air completel saturated with moisture. The distance between thes points is divided into 100 equal degrees.

Regnault has devoted much study in order to rende the air hygrometer scientifically useful, but without suc cess. And the utmost that can be claimed for it is tha it can be used as a *hygroscope*; that is, an instrume which shows approximately whether the air is more o less moist, without giving any indication as to the quan tity of moisture present. To this class belong the chimne ornaments, one of the most common forms of which i that of a small male and female figure, so arranged i reference to a little house, with two doors, that when it is moist the ma goes out, and the woman goes in, and *vice versâ* when it is fine. The are founded on the property which twisted strings or pieces of catgu possess, of untwisting when moist, and of twisting when dry.

As these hygroscopes only change slowly, their indications are alwa behindhand with the state of the weather; nor are they, moreover, ve exact.

370. **Problem on hygrometry.**—To calculate the weight P of volume of moist air V, the hygrometric state of which is E, the temper ture *t*, and the pressure H, the density of the vapour being $\frac{5}{8}$ that air.

From the second law of the mixture of gases and vapours, it will seen that the moist air is nothing more than a mixture of V cubic inch of dry air at $t°$, under the pressure H minus that of the vapour, and of cubic inches of vapour at $t°$ and the tension given by the hygromet state; these two values must, therefore, be found separately.

The formula $f = F \times E$ (362) gives the tension f of the vapour in the r E has been determined, and F is found from the tables. The tension being known, if f' is the tension of the air, $f+f'=H$, from which $f'=H$ $f=H-FE$.

The question consequently resolves itself into calculating the weight of cubic inches of dry air at $t°$, and the pressure $H-FE$, and then that of cubic inches of aqueous vapour also at $t°$, but under the pressure FE.

Now V cubic inches of dry air under the given conditions weigh $\frac{31\ V\ (H-FE)}{(1+at)\ 760}$, and we readily see from problem III. art. 355, that V bic inches of vapour at $t°$, and the pressure FE, weigh $\frac{5}{8} \times \frac{0.31\ VFE}{(1+at)\ 760}$.

dding these two weights, and reducing, we get

$$P = \frac{0{\cdot}31\ V\ (H - \frac{3}{8}\ FE)}{(1+at)\ 760}.$$

f the air were saturated we should have $E = 1$, and the formula would us be changed into that already found for the mixture of gases and turated vapours (355).

This formula contains, besides the weight P, many variable quantities , E, H, and t, and consequently, by taking successively each of these antities as unknown, as many different problems might be proposed.

371. **Correction for the loss of weight experienced by bodies eighed in the air.**—It has been seen in speaking of the balance, that he weight which it indicates is only an apparent weight, and is less than he real weight. The latter may be deduced from the former when it is emembered that every body weighed in the air loses a weight equal to hat of the displaced air (176). This problem is, however, very complicated, for not only does the weight of the displaced air vary with the mperature, the pressure, and the hygrometric state, but the volume of e body to be weighed, and that of the weights, vary also with the temrature; so that a double correction has to be made; one relative to the *eights*, the other to the body weighed.

Correction relative to the weights.—In order to make this correction let P be their weight in air, and Π their real weight *in vacuo*; further, let V e the volume of these weights at 0°, D the density of the substance of which they are made, and K its coefficient of linear expansion.

The volume V becomes $V\ (1+3Kt)$ at $t°$, hence this is the volume of air displaced by the *weights*. If μ be the weight of a cubic inch of air at t, and the pressure H at the time of weighing, we have

$$P = \Pi - \mu V(1+3Kt).$$

From the formula $P = VD$ (106) V may be replaced by $\frac{\Pi}{D}$, and the formula becomes

$$P = \Pi\left[1 - \frac{\mu(1+3Kt)}{D}\right] \quad . \quad . \quad . \quad . \quad (1)$$

which gives the value, in air, of a *weight* Π, when μ is replaced by its alue. But since μ is the weight of a cubic inch of air more or less moist, at the temperature t and the pressure H, its value may be calculated by means of the formula in the foregoing paragraph.

Correction relative to the body weighed.—Let p be the apparent weight of the body to be weighed, π its real weight *in vacuo*, d its density, k its coefficient of expansion, and t its temperature, by the same reasoning as above we have

$$p = \pi\left[1 - \frac{\mu(1+3kt}{d}\right] \quad . \quad . \quad . \quad . \quad (2)$$

By using the method of double weighing, and of a counterpoise whose apparent weight is p', the real weight π', the density d', and the coefficient k', and assuming that the pressure does not change, which is usually the case, we have again

$$p' = \pi'\left[1 - \frac{\mu(1+3k't')}{d'}\right] \quad . \quad . \quad . \quad . \quad (3)$$

If a and b are the two arms of the beam, we have in the first weighing $ap = bp$; and in the second $a\mathrm{P} = bp$, whence $p = \mathrm{P}$. Replacing P and p by their values deduced from the above equations, we have

$$\pi\left[1 - \frac{\mu(1+3kt)}{d}\right] = \Pi\left[1 - \frac{\mu(1+3\mathrm{K}t)}{\mathrm{D}}\right]$$

whence

$$\pi = \Pi\frac{1 - \frac{\mu(1+3\mathrm{K}t)}{\mathrm{D}}}{1 - \frac{\mu(1+3kt)}{d}}$$

which solves the problem.

CHAPTER VII.

CONDUCTIVITY OF SOLIDS, LIQUIDS, AND GASES.

372. **Transmission of heat.**—When we stand at a little distance from a fire or other source of heat we experience the sensation of warmth. The heat is not transmitted by the intervening air; it passes through it without raising its temperature, for if we place a screen before the fire the sensation ceases to be felt. The heat from the sun reaches us in the same manner. The heat, which, as in this case, is transmitted to a body from the source of heat without affecting the temperature of the intervening medium, is said to be *radiated.*

Heat is transmitted in another way. When the end of a metal bar is heated, a certain increase of temperature is presently observed along the bar. Where the heat is transmitted in the mass of the body itself, as in this case, it is said to be *conducted.* We shall first consider the transmission of heat by conduction.

373. **Conductivity of solids.**—Bodies conduct heat with differ degrees of facility. *Good conductors* are those which readily trans

at, such as are the metals ; while *bad conductors*, to which class belong e resins, glass, wood, and more especially liquids and gases, offer a eater or less resistance to the transmission of heat.

In order to compare roughly the conducting power or *conductivity* of fferent solids, Ingenhouss constructed the apparatus which bears his me, and which is represented in fig. 288. is a metal trough, in which, by means of bulures and corks, are fixed rods of the me dimensions, but of different materials; instance, iron, copper, wood, glass. These ds extend to a slight distance in the trough, d the parts outside are coated with wax, ich melts at 61°. The box being filled h boiling water, it is observed that the wax lts to a certain distance on the metallic s, while on the others there is no trace of ion. The conducting power is evidently greater in proportion as the x has fused to a greater distance. The experiment is sometimes dified by attaching glass balls or marbles to the ends of the rods by ans of wax. As the wax melts, the balls drop off, and this in the er of their respective conductivities. The quickness with which lting takes place, is however only a measure of the conducting power, in e the metals have the same or nearly the same specific heat.

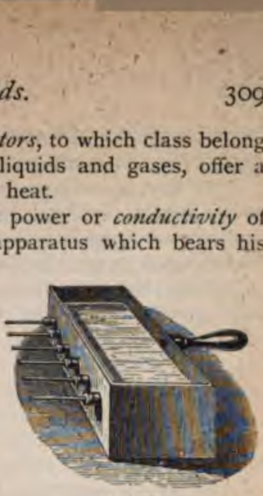


Fig. 288.

I. Despretz has compared the conducting powers of solids by means of apparatus represented in fig. 289. It is a bar in which small cavities made at intervals of 4 inches: these cavities contain mercury, and a icate thermometer is placed in each of them. This bar is exposed at end to a constant source of heat; the thermometers gradually rise il they indicate fixed temperatures, which are less according as the rmometers are farther from the source of heat. By this method spretz verified the following law: *If the distances from the source of*

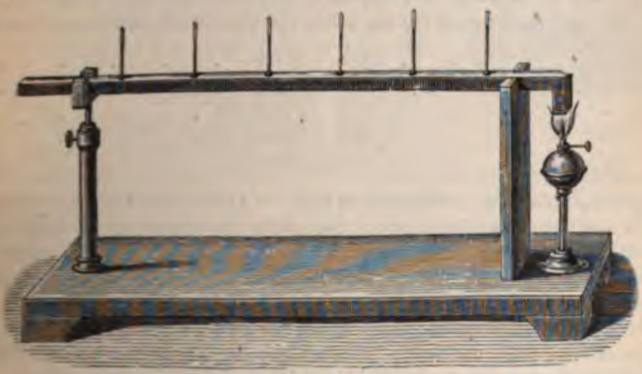


Fig. 289.

heat increase in arithmetical progression, the excess of temperature ove that of the surrounding air decreases in geometrical progression.

This law, however, only prevails in the case of very good conductor such as gold, platinum, silver and copper; it is only approximately tru for iron; zinc, lead, and tin, and does not apply at all to non-metalli bodies, such as marble, porcelain, etc.

Taking the conducting power of gold at 1000, Despretz has constructe the following table of conductivities :—

Platinum	981	Tin	304
Silver	973	Lead	179
Copper	897	Marble	23
Iron	374	Porcelain	12
Zinc	363	Brick earth	11

Wiedemann and Franz have made some valuable investigations on th conductivity of heat in metals. By making cavities in the bars, as i Despretz's method, their form is altered, and the continuity partially destroyed. Wiedemann and Franz have avoided this source of error b measuring the temperature of the bars in different places by applying t them the junction of a thermo-electric couple (380).

The metallic bars were made as regular as possible; one of the ends was heated to 100°, the rest of the bar being surrounded by air at a constant temperature. The thermo-electric couple was of small dimensions, in order not to extract too much heat.

By this method Wiedemann and Franz obtained results which differ considerably from those of Despretz. Representing the conductivity of silver by 100°, they found for the other metals the following numbers :

Silver	100·0	Steel	11·6
Copper	73·6	Lead	8·5
Gold	53·2	Platinum	8·4
Tin	14·5	Rose's alloy	2·8
Iron	11·9	Bismuth	1·8

Organic substances conduct heat badly. De la Rive and De Candolle have shown that woods conduct better in the direction of their fibres than in a transverse direction; and have remarked upon the influence which this feeble conducting power, in a transverse direction, exerts in preserving a tree from sudden changes of temperature, enabling it to resist alike a sudden abstraction of heat from within, and the sudden accession of heat from without. Tyndall has also shown that this tendency is aided by the low conducting power of the bark, which is in all cases less than that of the wood.

Cotton, wool, straw, bran, etc., are all bad conductors.

It has been attempted to determine the absolute quantity of heat which traverses in a second a plate of a substance a mètre square and a millimeter in thickness, the two sides being kept at a constant difference of 1°; this is called the *coefficient of conductivity*, *k*. The mean values are approximately obtained if Wiedemann's numbers are increased by ¼ and d by 10. Thus the coefficient of copper is 101. If the thickness of a n millimeters is d, and its two opposed faces are at the temperatures t_o the quantity of heat passing through is $k\frac{t-t_1}{d}$.

Senarmont's experiment.—It is only in homogeneous bodies eat is conducted with equal facility in all directions. If an aper- e made in a circular piece of ordinary glass covered with a thin of wax, and a platinum wire ignited by a voltaic current be held h the aperture, the wax will be melted round the hole in a circular Senarmont has made, on this principle, a series of experiments on nductivity of heat in crystals. A plate cut from a crystal of the r system was covered with wax, and a heated metallic point was gainst it. The part melted had a circular form ; but when plates of ls belonging to other systems were investigated in a similar manner. found that the form of the line of equal temperature, that is, the f the melted part, varied with the different s and with the position of the axes. In of uniaxial crystals cut parallel to the al axis it was an ellipse, the major axis of was in the direction of the principal axis. tes cut perpendicular to the principal axis a circle. In biaxial crystals the line was an ellipse.

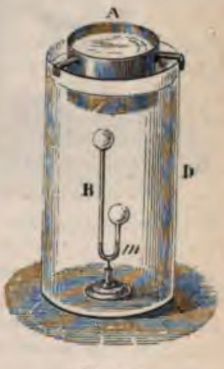


Fig. 290.

Conductivity of liquids.—The conduc- f liquids is very small, as is seen from the ng experiment : A delicate thermoscope sisting of two glass bulbs, joined by a tube, which there is a small index of coloured is placed in a large cylindrical glass ves- (fig. 290). This vessel is filled with water ordinary temperature, and a tin vessel, A, ing oil at a temperature of two or three d degrees, is dipped in it. The bulb near the vessel A is only very heated, and the index m moves through a very small distance. liquids give the same result. That liquids conduct very badly is monstrated by a simpler experiment. A long test tube is half filled ater and some ice so placed in it that it cannot rise to the surface. lining the tube and heating the surface of the liquid by means of a amp, the liquid at the top may be made to boil, while the ice at the remains unmelted.

retz made a series of experiments with an apparatus analogous to ich has been described, but he maintained the liquid in the vessel, constant temperature, and arranged a series of thermometers one he other in the vessel D. In this manner he found that the con- y of heat in liquids obeys the same laws as in solids, but is much eble. For example, the conductivity of water is $\frac{1}{95}$ that of copper. ow states that in regard to conducting power the following liquids the order given of their decreasing conductivity for heat : Mercury, water, solution of sulphate of copper, sulphuric acid, solution of s phate of zinc, solution of common salt.

376. **Manner in which liquids are heated.**—When a column liquid is heated at the bottom, ascending and descending currents produced. It is by these that heat is mainly distributed through t liquid, and not by its conductivity. These currents arise from the expa sion of the inferior layers, which, becoming less dense, rise in the liqui and are replaced by colder and denser layers. They may be ma visible by projecting bran or wooden sha ings into water, which rise and descend wi the currents. The experiment is arrang as shown in fig. 291. The mode in whi heat is propagated in liquids and in gases said to be by *convection.*

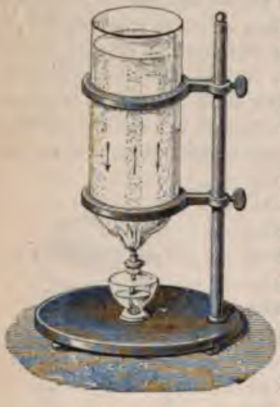


Fig. 291.

377. **Conductivity of gases.**—It is a di puted question whether gases have a tr conductivity; but certainly when they a restrained in their motion their conductivi is very small. All substances, for instanc between whose particles air remains statio ary, offer great resistance to the propagatio of heat. This is well seen in straw, eid down, and furs. The propagation of heat a gaseous mass is effected by means of t ascending and descending currents form in it, as is the case with liquids.

The following experiment originally devised by Grove is consider to prove that gases have a certain conductivity. In a glass vessel pr vided with delivery tubes by which any gases can be introduced, or b which it can be exhausted, is a platinum wire which can be heated redness by a voltaic battery. When the vessel is exhausted the platinu wire is gradually raised to a bright redness; on then allowing air enter, the luminosity is greatly diminished, and if the vessel be exhauste and then hydrogen admitted, the luminosity quite disappears. Th greater chilling of the wire in hydrogen than in air is considered b Magnus to be an effect of conduction; while Tyndall ascribes it to th greater mobility of the particles of hydrogen.

378. **Applications.**—The greater or less conductivity of bodies mee with numerous applications. If a liquid is to be kept warm for a lo time, it is placed in a vessel and packed round with non-conducting su stances, such as shavings, straw, bruised charcoal. For this purpo water pipes and pumps are wrapped in straw at the approach of fro The same means are used to hinder a body from becoming heate Ice is transported in summer by packing it in bran, or folding it flannel.

Double walls constructed of thick planks having between them a finely divided materials, such as shavings, sawdust, dry leaves, etc., retai heat extremely well; and are likewise advantageous in hot countries, f they prevent its access. During the night the windows are opened, while during the day they are kept close. Pure silica in the state of rock crystal is a better conductor than lead, but in a state of powder it conducts very badly. If a layer of asbestos is placed on the hand a red-hot iron ball can be held without inconvenience. Red-hot cannon balls can be wheeled to the gun's mouth in wooden barrows partially filled with sand. Lava has been known to flow over a layer of ashes underneath which was a bed of ice, and the non-conducting power of the ashes has prevented the ice from fusion.

The clothes which we wear are not warm in themselves; they only hinder the body from losing heat, in consequence of their spongy texture and the air they enclose. The warmth of bed covers and of counterpanes is explained in a similar manner. Double windows are frequently used in cold climates to keep a room warm—they do this by the non-conducting layer of air interposed between them. It is for the same reason that two shirts are warmer than one of the same material but of double the thickness. Hence too the warmth of furs, eider-down, etc.

The small conducting power of felt is used in the North of Europe in the construction of the *Norwegian stove*, which consists merely of a wooden box with a thick lining of felt on the inside. In the centre is a cavity in which can be placed a stew-pan provided with a cover. On the top of this is a lid, also made of felt, so that the pan is surrounded by a very badly conducting envelope. Meat, with water and suitable additions, is placed in the pan, and the contents are then raised to boiling. The whole is then enclosed in the box and left to itself; the cooking will go on without fire, and after the lapse of several hours it will be quite finished. The cooling down is very slow, owing to the bad conducting power of the lining; at the end of three hours the temperature is usually not found to have sunk more than from 10° to 15°.

That water boils more rapidly in a metallic vessel than in one of porcelain of the same thickness; that a burning piece of wood can be held close to the burning part with the naked hand, while a piece of iron heated at one end can only be held at a great distance, are easily explained by reference to their various conductivities.

The sensation of heat or cold which we feel when in contact with certain bodies is materially influenced by their conductivity. If their temperature is lower than ours, they appear colder than they really are, because from their conductivity heat passes away from us. If, on the contrary, their temperature is higher than that of our body, they appear warmer from the heat which they give up at different parts of their mass. Hence it is clear why carpets, for example, are warmer than wooden floors, and why the latter are warmer than stone floors.

CHAPTER VIII.

RADIATION OF HEAT.

379. **Radiant heat.**—It has been already stated (372) that heat co be transmitted from one body to another without altering the temperat of the intervening medium. If we stand in front of a fire we experie a sensation of warmth which is not due to the temperature of the air, if a screen be interposed the sensation immediately disappears, wh would not be the case if the surrounding air had a high temperatu Hence bodies can send out rays which excite heat, and which penet through the air without heating it, as rays of light through transpa bodies. Heat thus propagated is said to be *radiated*; and we shall the terms *ray of heat*, or *thermal* or *calorific ray*, in a similar sense to t in which we use the the term *ray of light* or *luminous ray*.

We shall find that the property of radiating heat is not confined luminous bodies, such as a fire or a red-hot ball, but that bodies of temperatures radiate heat. It will be convenient to make a distinct between *luminous* and *obscure* rays of heat.

380. **Detection and measurement of radiant heat.**—In demonstrat the phenomena of radiant heat, very delicate thermometers are requir and the thermo-electrical multiplier of Melloni is used for this purp with great advantage; for it not only indicates minute differences of te perature, but it also measures them with accuracy.

This instrument cannot be properly understood without a knowledge the principles of thermo-electricity, for which Book X. must be consult It may, however, be stated here, that when two different metals A an are soldered together at one end (fig. 292), the free ends being joined a wire, when the soldering C is heated, a current of electricity circula through the system; if, on the contrary, the soldering be cooled, a curr is also produced, but it circulates in exactly the opposite directions. a number of such pairs be alternately soldered together, as represent in fig. 293, the intensity of the current produced by heating the ends increased; or, what amounts to the same thing, a smaller degree of h will produce the same effect. Such an arrangement of a number thermo-electric pairs is called a *thermo-electric battery* or *pile*.

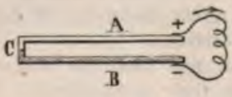


Fig. 292.

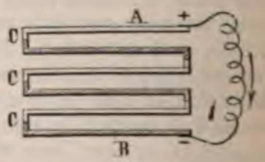


Fig. 293.

Melloni's thermo-multiplier consists of a thermo-electric pile connect with a delicate galvanometer. The thermo-electric pile is constructed number of minute bars of bismuth and antimony soldered together lternately, though kept insulated from each other, and contained in a ectangular box P, fig. 294. The terminal bars are connected with two

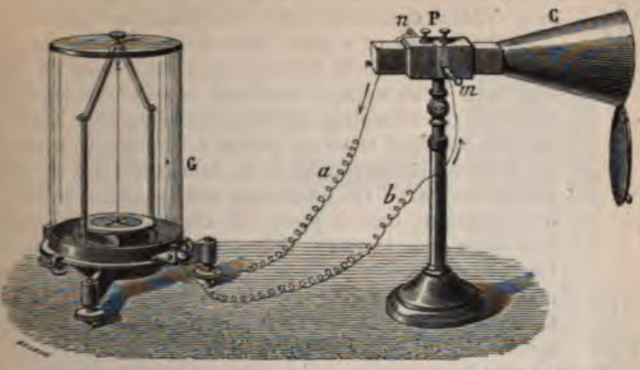


Fig. 294.

binding screws *m* and *n*, which in turn are connected with the galvanometer G by means of the wires *a* and *b*.

The galvanometer consists of a quantity of fine insulated copper wire coiled round a frame, in the centre of which a delicate magnetic needle is suspended by means of a silk thread. When an electric current is passed through this coil, the needle is deflected through an angle which depends on the intensity of the current. This angle is measured on a dial by an index connected with the needle.

It may then be sufficient to state that the thermo-electric pile being connected with the galvanometer by means of the wires *a* and *b*, an excess of temperature at one end of the pile causes the needle to be deflected through an angle which depends on the extent of this excess; and similarly if the temperature be depressed below that of the other end, a corresponding deflection is produced in the opposite direction. By arrangements of this kind Melloni was able to measure differences of temperature of $\frac{1}{5000}$th of a degree.

The object of the conical part C is to concentrate the thermal rays on the face of the pile.

381. **Laws of Radiation.**—The radiation of heat is governed by three laws :—

I. *Radiation takes place in all directions round a body.* If a thermometer be placed in different positions round a heated body, it indicates erywhere a rise in temperature.

II. *In a homogeneous medium, radiation takes place in a right line.* e, if a screen be placed in a right line which joins the source of heat nd the thermometer, the latter is not affected.

But in passing obliquely from one medium into another, as from air nto a glass, calorific like luminous rays become deviated, an effect known as *refraction*. The laws of this phenomenon are the same fo heat as for light, and they will be more fully discussed under the latte subject.

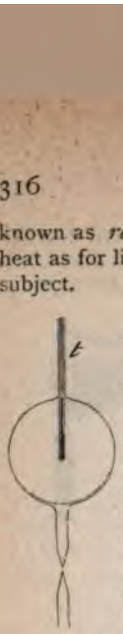


Fig. 295.

III. *Radiant heat is propagated in vacuo as well as i air.* This is demonstrated by the following experiment:—

In the bottom of a glass flask a thermometer is fixed i such a manner that its bulb occupies the centre of the flask (fig. 295). The neck of the flask is carefully narrowed b means of the blowpipe, and then the apparatus having bee suitably attached to an air pump, a vacuum is produced i the interior. This having been done, the tube is sealed a the narrow part. On immersing this apparatus in hot water or on bringing near it some hot charcoal, the thermomete is at once seen to rise. This could only arise from radiation through the vacuum in the interior, for glass is so bad a conductor, that the heat could not travel with this rapidity through the sides of the flask and the stem of the thermometer.

382. **Causes which modify the intensity of radiant heat.**—By th *intensity of radiant heat* is understood the quantity of heat received o the unit of surface. Three causes are found to modify this intensity; the temperature o the source of heat, its distance, and the obliquity of the caloric rays in reference to th surface which emits them. The laws which regulate these modifications may be thus stated:

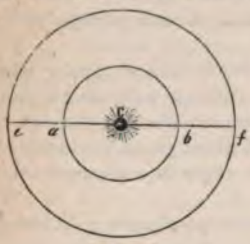


Fig. 296.

I. *The intensity of radiant heat is proportional to the temperature of the source.*

II. *The intensity is inversely as the squar of the distance.*

III. *The intensity is less, the greater th obliquity of the rays with respect to the radiating surface.*

The first law is demonstrated by placing a metallic box containing water at 10°, 20°, or 30°, successively at equal distances from the bulb o a differential thermometer. The temperatures indicated by the latter are then found to be in the same ratio as those of the box: for instance, if the temperature of that corresponding to the box at 10° be 2°, those o others will be 4° and 6° respectively.

The truth of the second law follows from the geometrical principle tha the surface of a sphere increases as the square of its radius. Suppose a hollow sphere, *ab* (fig. 296), of any given radius, and a source of heat, C, in its centre; each unit of surface in the interior receives a certain quantity of heat. Now, a sphere, *ef*, of double the radius will present a surface four times as great: its internal surface contains, therefore, four times as many units of surface, and as the quantity of heat emitted is the same, each unit must receive one-fourth the quantity.

To demonstrate the same law experimentally, a narrow tin plate bo is taken (fig. 297), filled with hot water, and coated on one side wit pblack. The thermo-battery with its conical reflector is placed so that face is at a certain definite distance, *co*, say 9 inches, from this box, d the cover having been lowered, the needle of the galvanometer is served to be deflected through 80°, for example.

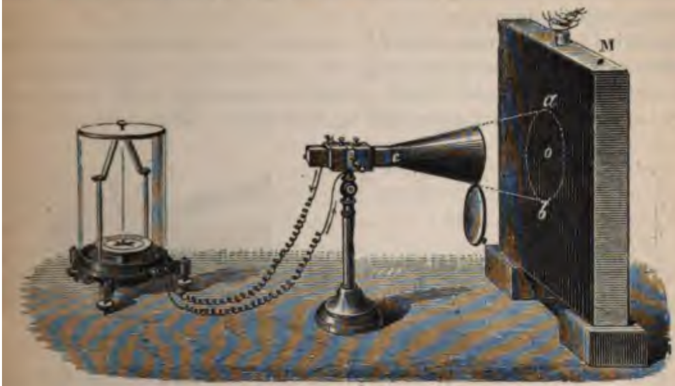


Fig. 297.

If now the battery is removed to a distance, CO, double that of *co*, the flection of the galvanometer remains the same, which shows that the ttery receives the same amount of heat; the same is the case if the ttery is removed to three or four times the distance. This result,

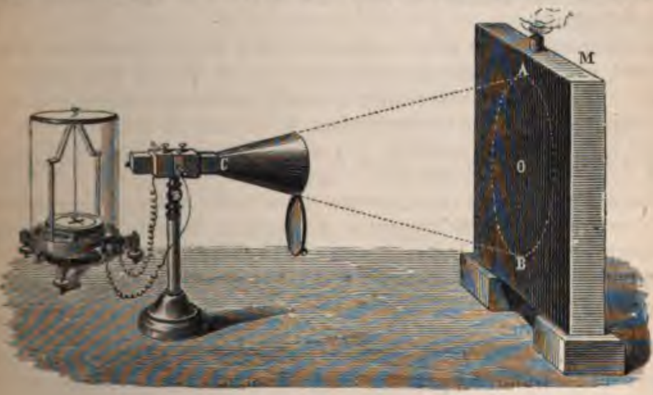


Fig. 298.

ugh apparently in opposition to the second law, really confirms it. r at first the battery only receives heat from the circular portion *ab* of side of the box, while, in the second case, the circular portion AB liates towards it. But, as the two cones ACB and *acb* are similar, and the height of ACB is double that of *acb*, the diameter AB is double that of *ab*, and therefore the area AB is four times as great as that of *ab*, for the areas of circles are proportional to the squares of the radii. But since the radiating surface increases as the square of the distance, while the galvanometer is stationary, the heat received by the battery must be inversely as this same square.

The third law is demonstrated by means of the following experiment, which is a modification of one originally devised by Leslie (fig. 299). P represents the thermo-multiplier which is connected with its galvanometer, and A, a metal cube full of hot water. The cube being firs

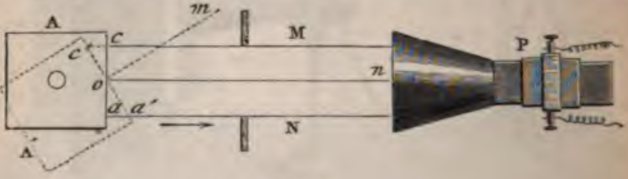


Fig. 299.

placed in such a position, A, that its front face *ac* is vertical, the deflection of the galvanometer is noted. Supposing it amounts to 45°, this represents the radiation from *ac*. If this now be turned in the direction represented by A′, the galvanometer is still found to mark 45°.

The second surface is larger than the first, and it therefore sends more rays to the mirror. But as the action on the thermometer is no greater than in the first case, it follows that in the second case, where the rays are oblique, the intensity is less than in the first case, where they are perpendicular.

In order to express this in a formula, let i be the intensity of the rays emitted perpendicularly to the surface, and i' that of the oblique rays. These intensities are necessarily inversely as the surfaces *ac* and *a′c′*, for the effect is the same in both cases, and therefore $i' \times$ surface $a'c' = i \times$ surface *ac*; hence $i' = i\,\frac{\text{surf. } ac}{\text{surf. } a'c'} = i\,\frac{ac}{a'c'} = i \cos aoa'$; which signifies that *the intensity of oblique rays is proportional to the cosine of the angle which these rays form with the normal to the surface*; for this angle is equal to the angle *aoa′*. This law is known as the *law of the cosine*; it is, however, not general; MM. Desains and De la Provostaye have shown that it is only true within very narrow limits, that is, only with bodies which, like lampblack, are entirely destitute of reflecting power (391).

383. **Mobile equilibrium. Theory of exchanges.**—Prevost of Geneva suggested the following hypothesis in reference to radiant heat, known as Prevost's *theory of exchanges*, which is now universally admitted. All bodies, whatever their temperature, constantly radiate heat in all directions. If we imagine two bodies at different temperatures placed near one another, the one at a higher temperature will experience a loss of heat, its temperature will sink, because the rays it emits are of greater intensity than those it receives; the colder body, on the contrary, will rise in temperature because it receives rays of greater intensity than

those which it emits. Ultimately the temperature of both bodies becomes the same, but heat is still exchanged between them, only each receives as much as it emits, and the temperature remains constant. This state is called the *mobile equilibrium of temperature.*

384. **Newton's law of cooling.**—A body placed in a vacuum is only cooled or heated by radiation. In the atmosphere it becomes cooled or heated by its contact with the air according as the latter is colder or hotter than the radiating body. In both cases the velocity of cooling or of heating—that is, *the quantity of heat lost or gained in a second*—is greater according as the difference of temperature is greater.

Newton has enunciated the following law in reference to the cooling or heating of a body: *The quantity of heat lost or gained by a body in a second is proportional to the difference between its temperature and that of the surrounding medium.* Dulong and Petit have proved that this law is not so general as Newton supposed, and only applies where the differences of temperature do not exceed 15° to 20°. Beyond that, the quantity of heat lost or gained is greater than that required by this law.

Two consequences follow from Newton's law:

i. When a body is exposed to a constant source of heat, its temperature does not increase indefinitely, for the quantity which it receives in the same time is always the same; while that which it loses increases with the excess of the temperature over that of the surrounding medium. Consequently a point is reached at which the quantity of heat emitted is equal to that absorbed, and the temperature then remains stationary.

ii. Newton's law, as applied to the differential thermometer, shows that its indications are proportional to the quantities of heat which it receives. If one of the bulbs of a differential thermometer receives rays of heat from a constant source, the instrument exhibits first increasing temperatures, but afterwards becomes stationary. In this case, the quantity of heat which it receives is equal to that which it emits. But the latter is proportional to the excess of the temperature of the bulb above that of the surrounding atmosphere, that is, to the number of degrees indicated by the thermometer; consequently, the temperature indicated by the ifferential thermometer is proportional to the quantity of heat it receives.

REFLECTION OF HEAT.

385. **Laws of reflection.**—When thermal rays fall upon a body they re, speaking generally, divided into two parts, one of which penetrates the ody, while the other rebounds as if repelled rom the surface like an elastic ball. This is aid to be *reflected.*

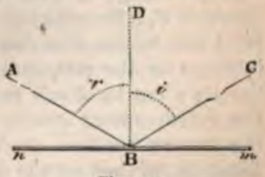


Fig. 300.

If *mn* be a plane reflecting surface (fig. oo), CB an *incident ray*, BD a line perpendicular to the surface called the *normal*, and A the *reflected ray*; the angle CBD is alled the *angle of incidence*, and DBA the ngle *of reflection.* The reflection of heat, like that of light, is governed the two following laws:—

I. *The angle of reflection is equal to the angle of incidence.*

II. *Both the incident and the reflected ray are in the same plane wi the normal to the reflecting surface.*

386. **Experimental demonstration of the laws of reflection of heat.** —This may be effected by means of Melloni's thermo-pile and also by the conjugate mirrors (388). Figure 301 represents the arrangeme

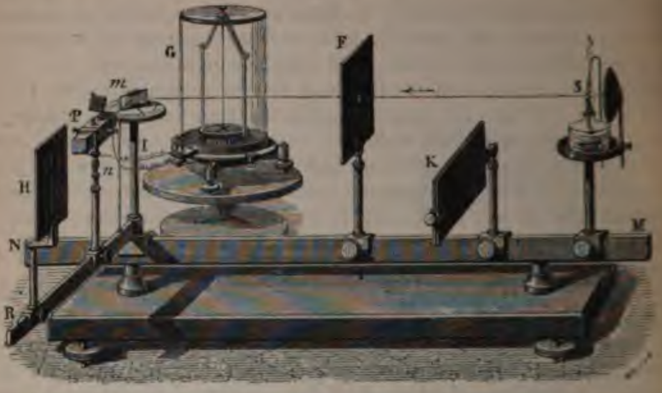


Fig. 301.

adopted in the former case. MN is a horizontal bar, about a mètre length graduated in millimeters, on which slide various parts, which ca be clamped by means of screws. The source of heat, S, is a platinu spiral, kept at a white heat in a spirit lamp. A screen, K, when raise cuts off the radiation from the source; a second screen, F, with an ape ture in the centre, gives the rays a parallel direction. At the other e is an upright rod, I, with a graduated dial, the zero of which is in th direction of MN, and therefore parallel to the pencil S*m*. In the centr of the dial is an aperture, in which turns an axis which supports metallic mirror *m*. About this axis turns an index, R, on which is fix the thermo-battery, P, in connection with the galvanometer, G. H is screen, the object of which is to cut off any direct radiation from th source of heat towards the battery. In order not to mask the battery, is not represented in the position it occupies in the experiment.

By lowering the screen K, a pencil of parallel rays, passing through th aperture F, falls upon the mirror *m*, and is there reflected. If the inde R is not in the direction of the reflected pencil, this latter does n impinge on the pile, and the needle of the galvanometer remains sta tionary; but by slowly turning the index R, a position is found at whic the galvanometer attains its greatest deviation, which is the case whe the battery receives the reflected pencil perpendicularly to its surfac Reading off then on the dial the position of a small needle perpendicul to the mirror, it is observed that this bisects the angle formed by th incident and the reflected pencil, which demonstrates the first law.

he second law is also proved by the same experiment, for the various es of the apparatus are arranged so that the incident and reflected are in the same horizontal plane, and therefore at right angles to the cting surface, which is vertical.

7. **Reflection from concave mirrors.**—*Concave mirrors* or *re- ors* are polished spherical or parabolic surfaces of metal or of glass, h are used to concentrate luminous or calorific rays in the same it.

e shall only consider the case of spherical mirrors. Fig. 303 repre- s two of these mirrors; fig. 302 gives a medial section, which is d the *principal section*. The centre C of the sphere to which the rror belongs is called the *centre of curvature*; the point A, the middle the reflector, is the *centre of the figure*; the straight line AB passing ough these points, is the *principal axis* of the mirror.

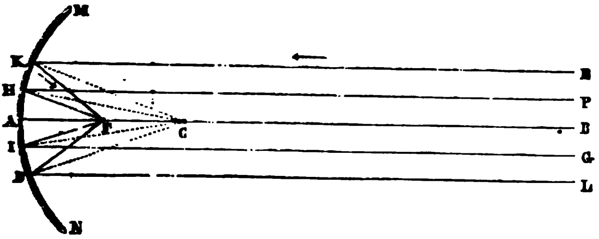


Fig. 302.

In order to apply to spherical mirrors the laws of reflection from plane faces, they are considered to be composed of an infinite number of in- itely small plane surfaces, each belonging to the corresponding tangent ne; the normals to these small surfaces are all radii of the same sphere, d therefore meet at its centre, the centre of curvature of the mirror.

Suppose now, on the axis AB of the mirror MM, a source of heat so tant that the rays EK, PH . . . . . which emanate from it may be sidered as a parallel. From the hypothesis that the mirror is com- sed of an infinitude of small planes, the ray EK is reflected from the ne K just as from a plane mirror; that is to say, CK being the rmal to this plane, the reflected ray takes a direction such that the gle CKF is equal to the angle CKE. The other rays, PH, GI . . . . . e reflected in the same manner, and all converge approximately towards e same point F, on the line AC. There is then a concentration of the ys in this point, and consequently a higher temperature than at any er point. This point is called the *focus*, and the distance from the cus to the mirror at A is the *focal distance*.

In the above figure the heat is propagated along the lines EKF, LDF, the direction of the arrows; but, conversely, if the heated body be ced at F, the heat is propagated along the lines FKE, FDL, so that rays emitted from the focus are nearly parallel after reflection.

388. **Verification of the laws of reflection.**—The following exp
ment, which was made for the first time by Pictet and Saussure,
which is known as the *experiment of the conjugate mirrors*, demonstr
not only the existence of the foci, but also the laws of reflection.
reflectors, M and N (fig. 303), are arranged at a distance of 4 to 5 y
and so that their axes coincide. In the focus of one of them, A, is pl
a small wire basket containing a red-hot iron ball. In the focus of

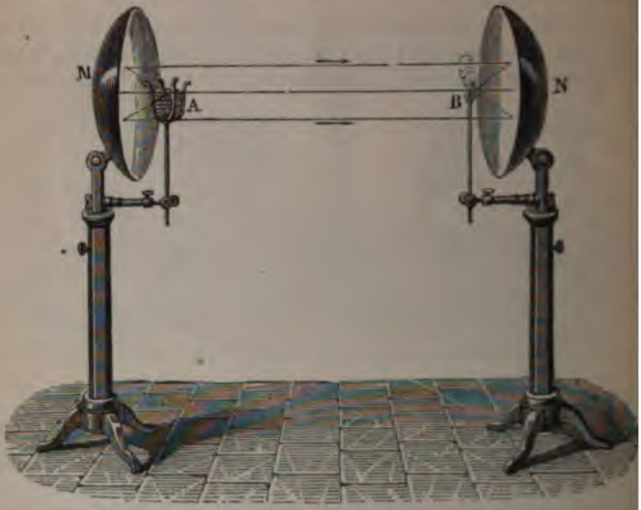


Fig. 303.

other is placed B, an inflammable body, such as gun-cotton or phosph
The rays emitted from the focus A are first reflected from the mirr
in a direction parallel to the axis (387), and impinging on the
mirror, N, are reflected so that they coincide in the focus B. Th
is so, is proved by the fact that the gun-cotton in this point take
which is not the case if it is above or below it.

The experiment also serves to show that light and heat are reflect
the same manner. For this purpose a lighted candle is placed
focus of A, and a ground-glass screen in the focus of B, when a lum
focus is seen on it exactly in the spot where the gun-cotton ig
Hence the luminous and the calorific foci are produced at the
point, and the reflection takes place in both cases according to the
laws, for it will be afterwards shown that for light the angle of refl
is equal to the angle of incidence, and that both the incident an
reflected rays are in the same plane perpendicular to the plane refl
surface.

In consequence of the high temperature produced in the foci of
cave mirrors they have been called *burning mirrors*. It is stated
Archimedes burnt the Roman vessels before Syracuse by means of

irrors. Buffon constructed burning mirrors of such power as to prove at the feat attributed to Archimedes was possible. The mirrors were ade of a number of silvered plane mirrors about 8 inches long by 5 road. They could be turned independently of each other in such a anner that the rays reflected from each coincided in the same point. Vith 128 mirrors and a hot summer's sun Buffon ignited a plank of rred wood at a distance of 70 yards.

389. **Reflection in a vacuum.**—Heat is reflected in a vacuum as well s in air, as is seen from the following experiment (fig. 304), due to Sir lumphry Davy. Two small concave eflectors were placed opposite each ther under the receiver of an air ump. In the focus of one was placed delicate thermometer, and in the cus of the other a platinum wire ade incandescent by means of a alvanic current. The thermometer as immediately seen to rise several egrees, which could only be due to eflected heat, for the thermometer did ot show any increase of temperature it were not exactly in the focus of e second reflector.

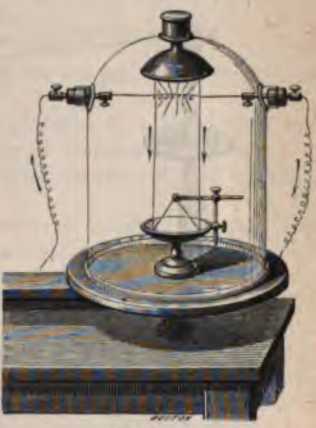


Fig. 304.

390. **Apparent reflection of cold.** If two mirrors are arranged as re-esented in fig. 304, and a piece of e is placed in one of the foci instead the red-hot ball, the surrounding mperature being greater than zero, a differential thermometer placed in e focus of the second reflector would exhibit a decrease in temperature several degrees. This appears at first to be caused by the emission of *igorific* rays from ice. It is, however, easily explained from what has en said about the mobile equilibrium of temperature (383). There is ll an exchange of temperature, but here the thermometer is the warmest dy. As the rays which the thermometer emits are more intense than ose emitted by the ice, the former gives out more heat than it receives, d hence its temperature sinks.

The sensation of cold experienced when we stand near a plaster or a ne wall whose temperature is lower than that of our body, or when we nd in front of a wall of ice, is explained in the same way.

391. **Reflecting power.**—The *reflecting power* of a substance is its perty of throwing off a greater or less proportion of incident heat.

This power varies in different substances. In order to study this ver in different bodies without having recourse to as many reflectors, lie arranged his experiments as shown in fig. 305. The source of t is a cubical canister, M, now known as *Leslie's cube*, filled with hot er. A plate, *a*, of the substance to be experimented upon is placed he axis of a reflecting mirror between the focus and the mirror. In this manner the rays emitted by the source are first reflected from mirror and impinge on the plate *a*, where they are again reflected converge to a focus between the plate and the mirror, in which poi differential thermometer is placed. The reflector and the thermom are always in the same position, and the water of the cube is always at 100°, but it is found that the temperature indicated by the thermon varies with the nature of the plate. This method gives a mea

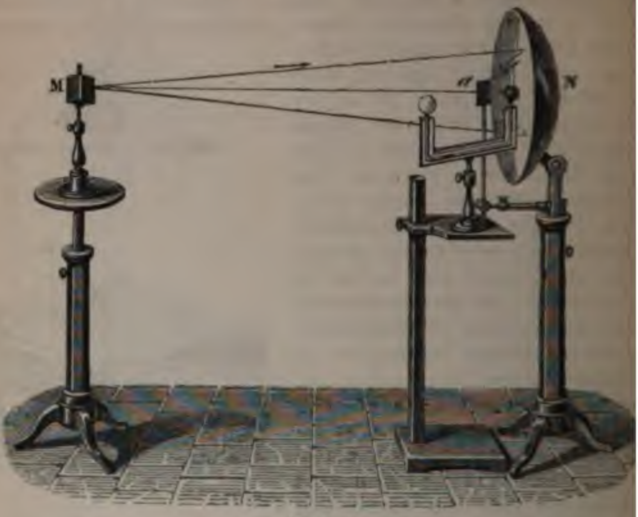


Fig. 305.

determining, not the absolute reflecting power of a body, but its p relatively to that of some body taken as a standard of comparison. from what has been said on the application of Newton's law to differential thermometer, the temperatures which this instrument indi are proportional to the quantities of heat which it receives. Hence, the above experiment, a plate of glass causes the temperature to ri and a plate of lead 6°, it follows that the quantity of heat reflected b latter is six times as great as that reflected by the former. For the emitted by the source remains the same, the concave reflector rec the same portion, and the difference can only arise from the refle power of the plates *a*.

By this method Leslie determined the reflecting powers of the follo substances, relatively to that of brass, taken as 100 :—

Polished brass	100	Indian ink	
Silver	90	Amalgamated tin	
Polished tin	80	Glass	
Steel	70	Oiled glass	
Lead	60	Lampblack	

The numbers only represent the relative reflecting power as compared ith that of brass. Their *absolute power* is the *relation of the quantity f heat reflected to the quantity of heat received.* Melloni first determined he absolute reflecting power of a certain number of bodies. Desains and e la Provostaye, who also examined it for certain metals, obtained the llowing results by means of Melloni's thermo-multiplier (380), the heat eing reflected at an angle of 50° :—

ilver plate	0·97	Steel	0·82
old	0·95	Zinc	0·81
rass	0·93	Iron	0·77
latinum	0·83	Cast iron	0·74

We shall presently see (395) what are the causes which modify the eflecting power.

392. **Absorbing power.**—The *absorbing power* of a body is its proerty of allowing a greater or less quantity of incident heat to pass into s mass. Its absolute value is the ratio of the quantity of heat absorbed the quantity of heat received.

The absorbing power of a body is always inversely as its reflecting ower : a body which is a good absorbent is a bad reflector, and *vice versâ.* was formerly supposed that the two powers were exactly complemenry, that the sum of the reflected and absorbed heat was equal to the tal quantity of incident heat. This is not the case ; it is always less : e incident heat is divided into three parts—1st, one which is absorbed ; nd, another which is reflected regularly—that is, according to laws preously demonstrated (385) ; and a third, which is irregularly reflected in l directions, and which is called *scattered* or *diffused heat.*

In order to determine the absorbing power of bodies, Leslie used the pparatus which he employed in determining the reflecting powers (391). ut he suppressed the plate *a*, and placed the bulb of the thermometer in e focus of the reflector. This bulb being then covered successively ith lampblack, or varnish, or with gold, silver, or copper foil, etc., the ermometer exhibited a higher temperature under the influence of the urce of heat, M, according as the substance with which the bulb was overed absorbed more heat. Leslie found in this way that the absorbg power of a body is greater the less its reflecting power. In these periments, however, the relation of the absorbing powers cannot be educed from that of the temperatures indicated by the thermometer, for ewton's law is not exactly applicable in this case, as it only prevails for dies whose substance does not vary, and here the covering of the bulb ried with each observation. But we shall presently show (394) how e comparative absorbing powers may be deduced from the ratios of the issive powers.

Taking as a source of heat a canister filled with water at 100°, Melloni nd by means of the thermo-multiplier the following relative absorbing wers :—

mpblack	100	Indian ink	85
hite lead	100	Shellac	72
nglass	91	Metals	13

393. **Radiating power.**—The *radiating* or *emissive power* of a is its capability of emitting at the same temperature and with the extent of surface greater or less quantities of heat.

The apparatus represented in fig. 305 was also used by Leslie in mining the radiating power of bodies. For this purpose the bulb thermometer was placed in the focus of the reflector, and the faces canister M were formed of different metals, or covered with di substances, such as lampblack, paper, etc. The cube being fille hot water, at 100°, and all other conditions remaining the same, turned each face of the cube successively towards the reflectors, and the temperature each time. That face which was coated with black caused the greatest elevation of temperature, and the metal the least. Applying Newton's law, and representing the heat e by lampblack as 100, Leslie formed the following table of ra powers :—

Lampblack	100	Isinglass . . . .
White lead	100	Tarnished lead . .
Paper	98	Mercury . . . .
Sealing wax	95	Polished lead . . .
Ordinary white glass . .	90	Polished iron . . .
Indian ink	88	Tin, gold, silver, copper, etc.

It will be seen that, in this table, the order of the bodies is exac reverse of that in the tables of reflecting powers.

The radiating powers of several substances were determin Melloni by the same method as that of Leslie, but using the th multiplier instead of the differential thermometer. This has als been done more exactly by Dessains and De la Provostaye, who us same instrument, but avoided certain sources of error incidental to pr methods. They found in this manner the following numbers con with lampblack as 100 :—

Platinum foil	10·80	Pure silver laminated . .
Burnished platinum . .	9·50	„ burnished . .
Silver deposited chemically	5·36	„ deposited chemically and burnished . .
Copper foil	4·90	
Gold leaf	4·28	

It appears, therefore, that the radiating power found by Leslie f metals is too large.

394. **Identity of the absorbing and radiating powers.**—The a ing power of a body cannot be accurately deduced from its refl power, because the two are not exactly complementary. But the a ing power would be determined if it could be shown that in the same it is equal to the radiating power. This conclusion has been dra Dulong and Petit from the following experiments :—In a large glass blackened on the inside, was placed a thermometer at a certain te ture, 15° for example ; the globe was kept at zero by surrounding i ice, and having been exhausted by means of a tubulure connecte

the air pump, the time was noted which elapsed while the thermometer fell through 5°. The experiment was then made in the contrary direction; that is, the sides of the globe were heated to 15°, while the thermometer was cooled to zero : the time was then observed which the thermometer occupied in rising through 5°. It was found that this time was exactly the same as that which the thermometer had taken in sinking through 5°, and it was thence concluded that the radiating power is equal to the absorbing power for the same body, and for the same difference between its temperature and the temperature of the surrounding medium, because the quantities of heat emitted or absorbed in the same time are equal.

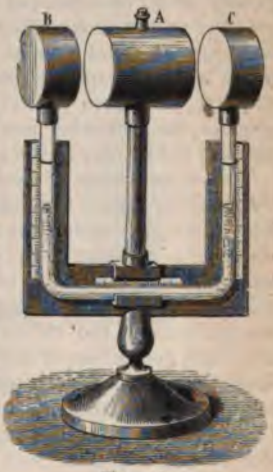


Fig. 306.

This point may also be demonstrated by means of the following apparatus devised by Ritchie. Fig. 306 represents what is virtually a differential thermometer, the two glass bulbs of which are replaced by two cylindrical reservoirs B and C, of metal, and full of air. Between them is a third and larger one A, which can be filled with hot water by means of a tubulure. The faces of B and of A, which face the right, are coated with lampblack ; those of C and A, which face the left, are either painted white, or are coated with silver foil. Thus of the two faces opposite each other, one is black and the other white ; hence when the cylinder A is filled with hot water, its white face radiates towards the black face of B, and its black face towards the white face of C. Under these circumstances the liquid in the stem does not move, indicating that the two reservoirs are at the same temperature. On the one hand, the greater emissive power of the black face of A is compensated by the smaller absorptive power of the white face of C ; while, on the other hand, the feebler radiating power of the white face of A is compensated by the greater absorbing power of the black face of B.

The experiment may be varied by replacing the two white faces by discs of paper, glass, porcelain, &c.

395. **Causes which modify the reflecting, absorbing, and radiating powers.**—As the radiating and absorbing powers are equal, any cause which affects the one affects the other also. And as the reflecting power varies in an inverse manner, whatever increases it diminishes the radiating and absorbing powers, and *vice versâ.*

It has been already stated that these different powers vary with different bodies, and that metals have the greatest reflecting power, and lampblack the feeblest. In the same body these powers are modified by the degree of polish, the density, the thickness of the radiating substance, the obliquity of the incident or emitted rays, and, lastly, by the nature of the source of heat.

It has been usually assumed that the reflecting power increases with the polish of the surface, and that the other powers diminish therewith. But Melloni showed that by scratching a polished metallic surface its reflecting power was sometimes diminished and sometimes increased. This phenomenon he attributed to the greater or less density of the reflecting surface. If the plate had been originally hammered, its homogeneity would be destroyed by this process, the molecules would be closer together on the surface than in the interior, and the reflecting power would be increased. But if the surface is scratched, the internal and less dense mass becomes exposed, and the reflecting power diminished. On the contrary, in a plate which has not been hammered, and which is homogeneous, the reflecting power is increased when the plate is scratched, because the density at the surface is increased by the scratches.

The experiments of Leslie, Rumford, and Melloni further prove, that the thickness of the radiating substance also modifies its emissive power. The latter philosopher found that when the faces of a cube filled with water at a constant temperature were varnished, the emissive power increased with the number of layers up to 16 layers, and that above that point it remained constant, whatever the number. He calculated that the thickness of the 16 layers was 0·04 of a millimeter. With reference to metals, gold leaves of 0·008, 0·004, and 0·002 of a millimeter in thickness, having been successively applied on the sides of a cube of glass, the diminution of radiant heat was the same in each case. It appears therefore that, between certain limits, the thickness of the radiating layer of metal is without influence.

The absorbing power varies with the inclination of the incident rays. It is greatest at the normal incidence, that is, at right angles; and it diminishes in proportion as the incident rays deviate from the normal. This is one of the reasons why the sun is hotter in summer than in winter, because, in the former case, the solar rays are less oblique.

The radiating power of gaseous bodies in a state of combustion is very weak, as is seen by bringing the bulb of a thermometer near a hydrogen flame, the temperature of which is very high. But if a platinum spiral be placed in this flame, it assumes the temperature of the flame, and radiates a considerable quantity of heat, as is indicated by the thermometer. It is for an analogous reason that the flames of oil and of gas lamps radiate more than a hydrogen flame, in consequence of the excess of carbon which they contain, and which, not being entirely burned, becomes incandescent in the flame.

396. **Melloni's researches on radiant heat.**—For our knowledge of the phenomena of the reflection, emission, and absorption of heat which have up to now been described, science is indebted mainly to Leslie. But since his time the discovery of other and far more delicate modes of detecting and measuring heat has not only extended and corrected our previous knowledge, but has led to the discovery of other phenomena of radiant heat, which without such improved means must have remained unknown.

This advance in science is due to an Italian philosopher, Melloni, who first applied the thermo-electric pile, invented by Nobili, to the measure t of very small differences of temperature; a method of which a pre- nary account has already been given.

his experiments Melloni used five sources of heat—1st, a Locatelli's —one, that is, without a glass chimney, but provided with a reflector 307); 2nd, an Argand lamp, that is, one with a chimney and a double ght; 3rd, a platinum spiral, kept red hot by a spirit lamp (fig. 308);

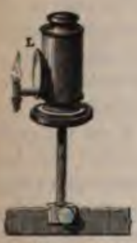


Fig. 307.

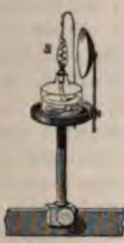


Fig. 308.

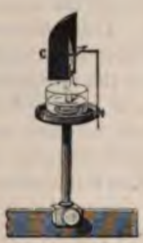


Fig. 309.

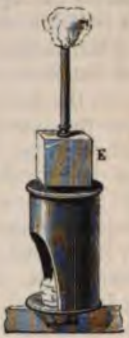


Fig. 310.

a blackened copper plate, kept at a temperature of about 400 degrees spirit lamp (fig. 309); 5th, a copper cube, blackened on the outside filled with water at 100° (fig. 310).

7. **Dynamical theory of heat.**—Before describing the results ar- l at by Melloni and others, it will be convenient to state here the view generally taken as to the mode in which heat is propagated. For tional information the chapter on the Mechanical Theory of Heat and ook on Light should be read. According to what has been already d, a hot body is nothing more than one whose particles are in a state bration. The higher the temperature of the body the more rapid are vibrations, and a diminution in temperature is but a diminished lity of vibration of the particles. The propagation of heat through a s due to a gradual communication of this vibratory motion from the ed part to the rest of the bar. A good conductor is one which readily up and transmits the vibratory motion from particle to particle, a bad conductor is one which takes up and transmits the motion difficulty. But even through a good conductor the propagation of motion is comparatively slow; how then are we to explain the ntaneous perception of heat experienced when a screen is removed a fire, or when a cloud is drifted from the face of the sun? In this the heat passes from one body to another without affecting the tem- ture of the medium which transmits it. In order to explain these omena, it is imagined that all space, the interplanetary spaces as well e interstices in the hardest crystal or the heaviest metal, in short, r of any kind, is permeated by a medium having the properties of a of infinite tenuity called *ether*. The particles of a heated body in a state of intensely rapid vibration, communicate their motion to

the ether around them, throwing it into a system of waves which travel through space and pass from one body to another with the velocity of light. When the undulations of the ether reach a given body, the motion is again delivered up to the particles of that body, which in turn begin to vibrate, that is, the body becomes heated. This passage of motion through the hypothetical ether is termed radiation, and a so called ray of heat is merely the direction of the motion of one series of waves.

It will facilitate the understanding of this to consider the analogous mode in which sound is produced and propagated. A sounding body is one whose entire mass is in a state of vibration ; the more rapid the rate of vibration, the more acute the sound ; the slower the rate of vibration, the deeper the sound. This vibratory motion is communicated to the surrounding air, by means of which the vibrations reach the auditory nerve and there produce the sensation of sound. If a metal ball be heated, say to the temperature of boiling water, we can ascertain that it radiates heat, although we cannot see any luminosity ; and if its temperature be gradually raised, we see it become successively of a dull red, bright red and dazzling white. Here it is assumed that at each particular temperature the heated body emits waves of a definite length ; in other words, its particles vibrate in a certain period. As its temperature rises it sends out other and more rapid undulations, which coexist however with all those which it had previously emitted. Thus the motion at each successive temperature is compounded of all preceding ones.

It has been seen that vibrations of the air below and above a certain rate do not affect the auditory nerve ; it can only take up and transmit to the brain vibrations of a certain periodicity. So too with the vibrations which produce heat. The optic nerve is insensible to a large number of wave lengths. It can apprehend only those waves that form the visible spectrum. If the rate of undulation be slower than the red or faster than the violet, though intense motion may pass through the humours of the eye and fall upon the retina, yet we shall be utterly unconscious of the fact, for the optic nerve cannot take up and respond to the rate of vibrations which exist beyond the visible spectrum in both directions. Hence these are termed *invisible* or *obscure* rays. A vast quantity of these obscure rays are emitted by flames which, though intensely hot, are yet almost non-luminous, such as the oxy-hydrogen flame, or that of a Bunsen's burner ; for the vibrations which these emit, though capable in part of penetrating the media of the eye, are incapable of exciting in the optic nerve the sensation of light.

398. **Thermal analysis of solar light.**—When a solar ray (fig. 311), admitted through an aperture in a dark room, is concentrated on a prism of rock salt by means of a lens of the same material, and then after emerging from the prism is received on a screen, it will be found to present a band of colours in the following order : red, orange, yellow, green, blue, and violet. This is called the *spectrum*.

If now a narrow and delicate thermo-pile be placed successively on the space occupied by each of the colours, it will be scarcely affected on the violet, but in passing over the other colours it will indicate a gradual se of temperature, which is greatest at the red. Painters thus, guided y a correct but unconscious feeling, always speak of blue and green olours as cold, and of red and orange as warm tones. If the pile be now oved in the same direction beyond the limits of the luminous spectrum, e temperature will gradually rise up to CP, at which it attains its aximum. From this point the pile indicates a decrease of temperature til it reaches a point, O, where it ceases to be affected. This point is bout as distant from R as the latter is from V; that is, there is a region which thermal effects are produced extending as far beyond the red nd of the spectrum in one direction as the entire length of the visible

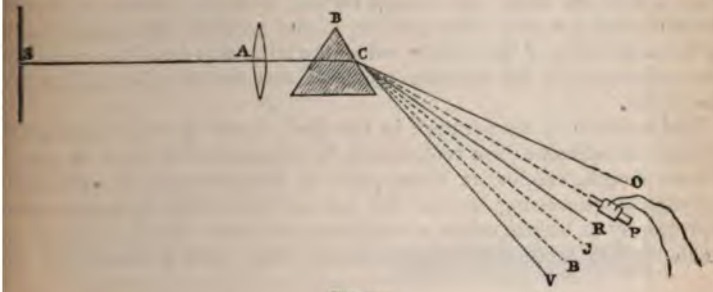


Fig. 311.

ectrum is in the other. In accordance with what we have stated, the n's light consists of rays of different rates of vibration; by their passge through the prism they are unequally broken or refracted; those of eatest wave length or slowest vibrating period are least bent aside, or e said to be the least refrangible, while those with shorter wave lengths e the most refrangible.

These non-luminous rays outside the red are called the extra or ultrad rays, or sometimes the *Herschelian* rays, from Sir W. Herschel, who st discovered their existence.

If in the above case prisms of other materials than rock salt be used, e position of maximum heat will be found to vary with the nature of e prism, a fact first noticed by Seebeck. Thus with a prism of ater it is in the yellow; with one of crown glass, in the middle of the d, and so on. These changes are due, as Melloni subsequently found, to e circumstance that prisms of different materials absorb rays of different frangibility to unequal extents. But rock salt practically allows heats all kinds to pass with equal facility, and thus gives a normal spectrum.

399. **Tyndall's researches.**—Prof. Tyndall has recently investigated e spectrum produced by the electric light, and has arrived at some ghly important results. His mode of experimenting was as follows:—e electric light was produced between charcoal points by a Grove's ttery of fifty cells. The beam, rendered parallel by a double rock salt s, was caused to pass through a narrow slit, and then through a second s of rock salt; the slices of white light thus obtained being decomposed a prism of the same material. To investigate the thermal conditions

of the spectrum a *linear* thermo-electric pile was used ; that is, one co
sisting of a number of elements arranged in a line, and in front of whi
was a slit that could be narrowed to any extent. The instrument w
mounted on a movable bar connected with a fine screw, so that
turning a handle the pile could be pushed forward through the small
space. On placing this apparatus, originally devised by Melloni for
researches on the solar spectrum, successively in each part of the spectr
of the electric light, the heating effected at various points near ea
other was determined by the indications of a very delicate galvanome
As in the case of the solar spectrum, the heating effect gradually
creased from the violet end towards the red, and was greatest in the d
space beyond the red. The position of the greatest heat was about
far from the limit of the visible red as the latter was from the green, a
the total extent of the invisible spectrum was found to be twice that
the visible.

The increase of temperature in the dark space is very considera
If thermal intensities are represented by perpendicular lines of prop
tionate length, erected at those parts of the spectrum to which t
correspond, on passing beyond the red end these lines increase rapi
and greatly in length, reach a maximum, and then fall somewhat m
suddenly. If these lines are connected, they form a curve (fig. 3

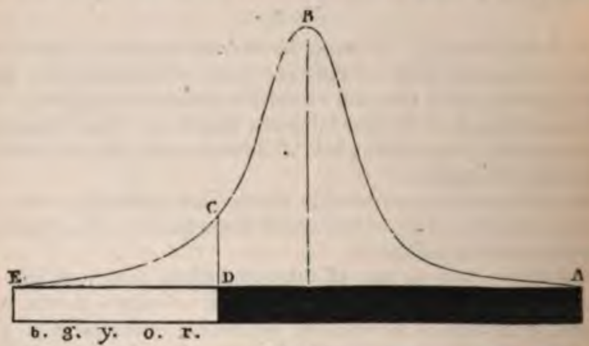


Fig. 312.

which beyond the red represents a massive peak, which quite dwarfs
its magnitude that of the visible spectrum. In fig. 313 the dark parts
the end represent the obscure radiation. The curve is based in the man
above stated, on the results obtained by Prof. Tyndall with the elec
light. The upper curve, in fig. 313, represents the spectrum of so
light from the experiments of Müller with a rock salt prism, while
lower curve represents the results obtained with the use of a flint gl
prism, which is thus seen to absorb some of the ultra-red radiation.

Prof. Tyndall found that by interposing various substances, more es
cially water, in certain thicknesses, in the path of the electric light,
ultra-red radiation was greatly diminished, the peak was not so lo

w aqueous vapour would, like water, absorb the obscure rays. And st probably the reason why the obscure part of the spectrum of the ar light is not so intense as in the case of the electric light, is that the cure rays have been already partially absorbed by the aqueous vapour he atmosphere. If a solar spectrum could be produced outside the osphere, it doubtless would give a spectrum more like that of the tric light, which is uninfluenced by the atmospheric absorption.

his has been remarkably confirmed in other ways. Melloni observed the position of the maximum in the solar spectrum differs on differ- days; which is probably due to the varying absorption of the atmo- re, in consequence of its varying hygrometric state. Recently, hi, in Rome, has found the same shifting of the maximum to occur e different seasons of the year; for in winter, when there is least ture in the atmosphere, the maximum is farther from the red than mmer, when the aqueous vapour in the air is most abundant. An rtant observation on the luminous rays has also been made by Cooke, merica, who found that the faint black lines in the solar spectrum buted to the absorption of light by our atmosphere (see book on cs) are chiefly caused by the presence of aqueous vapour.

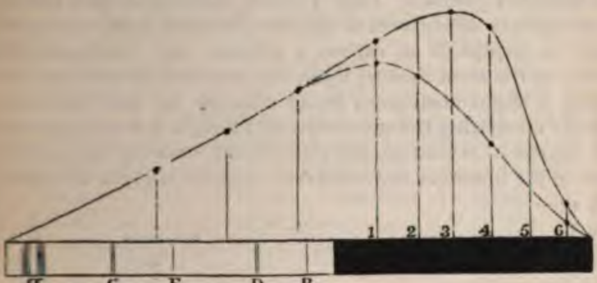


Fig. 313.

o. **Luminous and obscure radiation.**—It has been stated that radiation from a luminous object, a gas flame for example, is of mposite character; a portion consists of what we term light, but r greater part consists of heat rays, which are insensible to our , being unable to affect the optic nerve. When this mixed radiation upon the blackened face of a thermo-electric pile, the whole of it ken to be absorbed, the light by this act being converted into heat, affecting the instrument proportionally with the purely calorific rays. total radiation of a luminous source, expressed in units of heat or , can thus be measured. By introducing into the path of the rays dy capable of stopping either the luminous or the obscure radiation an ascertain by the comparative action on the pile the relative tities of heat and light radiated from the source. Melloni sought this by passing a luminous beam through a layer of water con- g alum in solution; a liquid which he found in previous experiments absorbed all the radiation from bodies heated under incandescen Comparing the transmission through this liquid—which allowed t luminous part of the beam to pass, but quenched the obscure portion with the transmission through a plate of rock salt—which affect neither the luminous nor the obscure radiation, but gave the loss due reflection—Melloni revealed the astonishing fact that 90 per cent. of t radiation from an oil flame and 99 per cent. of the radiation from a alcohol flame consist of invisible calorific rays. This proportion has bee still further increased by the recent experiments of Prof. Tyndall, w employed a liquid free from the objections which have caused a slig error in Melloni's method. Prof. Tyndall discovered that iodine, whi opaque to light, is transparent to the obscure heat rays. Dissolving th substance in bisulphide of carbon, a solution was obtained which w impervious to the most intense light, but wonderfully pervious to radia heat; only a slight absorption being effected by the bisulphide. B successively comparing the transmission through the transparent liqui and the transmission through the same liquid rendered opaque by iodin the value of the luminous radiation from various sources was found to b as follows :—

Source	Luminous	Obscure
Red-hot spiral	0	100
Hydrogen flame	0	100
Oil flame	3	97
Gas flame	4	96
White-hot spiral	4·6	95·4
Electric light	10	90

Here by direct experiment the ratio of luminous to obscure rays i the electric light is found to be 10 per cent. of the total radiation. B prismatic analysis, the curve shown in fig. 312 was obtained, graph cally representing the proportion of luminous to obscure rays in th electric light; by calculating the areas of the two spaces in the dia gram, the obscure portion is found to be nearly 10 times as large as th luminous.

401. **Transmutation of obscure rays.**—We shall find, in speaking o the luminous spectrum, that beyond the violet there are rays which ar invisible to the eye, but which are distinguished by their chemical action and are spoken of as the *actinic* or chemical rays; they are also known a the *Ritteric* rays, from the philosopher who first discovered their existence

As we shall also see in the book on Optics, Prof. Stokes has succeede in converting these rays into rays of lower refrangibility, which the became visible; so Prof. Tyndall has recently effected the correspondin but inverse change, and has increased the refrangibility of the Herschelian or extra red rays, and thus rendered them visible.

Prof. Tyndall worked with the electric light. The charcoal points were placed in front of a concave silvered glass mirror in such a manner that the rays from the points after reflection were concentrated to a focus about 6 inches distant. On the path of the beam was interposed a cell ll of a solution of iodine in bisulphide of carbon, which, as we have en, has the power of completely stopping all luminous radiation, but ves free passage to the non-luminous rays. On now placing in the cus of the beam thus sifted a piece of platinum, this was raised to candescence by the impact of perfectly invisible rays. In like manner piece of charcoal *in vacuo* was heated to redness.

By a proper arrangement of the charcoal points a metal may be raised whiteness, and the light now emitted by the metal yields on prismatic alysis a brilliant luminous spectrum, which is thus entirely derived m the invisible rays beyond the red.

To the new phenomena here described, this transmutation of non-minous into luminous heat, Prof. Tyndall has applied the term *lorescence.*

When the eye was cautiously placed in the focus, guarded by a small le being pierced in a metal screen, so that the converged rays should ly enter the pupil and not affect the surrounding part of the eye, no pression of light was produced, and there was scarcely any sensation of at. A considerable portion was absorbed by the humours of the eye, t yet a powerful beam undoubtedly reached the retina; for, as Prof. yndall showed by a separate experiment, about 18 per cent. of the scure radiation from the electric light passed through the humours of e ox's eye.

402. **Transmutation of thermal rays.**—Melloni was the first who amined extensively and accurately the absorption of heat by solids nd liquids. The apparatus he employed is represented in the annexed gure (314), where AB is the thermo-electric pile; *a* is a support for the

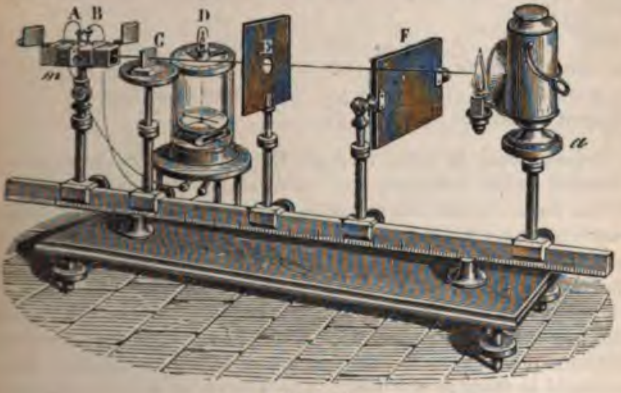


Fig. 314.

rce of heat, in this case a Locatelli's lamp; F and E are screens, and s a support for the body experimented upon; while *m* is the pile, and he galvanometer.

he various sources of heat used by Melloni in his experiments have e already (396) enumerated.

To express the power which bodies have of transmitting heat, Mell used the term *diathermancy*: diathermancy bears the same relation radiant heat that transparency does to light; and in like manner power of stopping radiant heat is called *athermancy*, which thus co sponds to opacity for light. In experimenting on the diathermancy liquids, Melloni used glass troughs with parallel sides, the thickness the liquid layer being 0·36 in. The radiant heat of an Argand lamp a glass chimney was first allowed to fall directly on the face of the pi and the deflection produced in the galvanometer taken as the total radi tion; the substance under examination was then interposed, and deflection noted. This corresponded to the quantity of heat transmitted by the substance. If t indicate this latter number, and t' the total radi tion, then

$$t' : t :: 100 : x$$

which is the percentage of rays transmitted. Thus, calling the total radiation 100, Melloni found that

Bisulphide of carbon transmitted	63
Olive oil ,, ...	30
Ether ,, ...	21
Sulphuric acid ,, ...	17
Alcohol ,, ...	15
Solution of alum or sugar ,, ...	12
Distilled water ,, ...	11

In experimenting with solids the substances were cut into plates inch in thickness, and it was found that of every 100 rays there transmitted by

Rock salt	92	Selenite	
Iceland spar and plate glass .	62	Alum	
Smoky quartz	57	Sulphate of copper . . .	
Transparent carbonate of lead	52		

The transmission of heat through liquids has been re-examined Prof. Tyndall in the following way:—Instead of employing a glass vess to hold the liquids under examination, he made use of a little cell who ends were stopped by parallel plates of rock salt. The plates we separated by a ring of brass, with an aperture on the top through which the liquid could be poured. As this plate could be changed at will liquid layers of various thicknesses were easily obtainable, the apparatus being merely screwed together and made liquid tight by paper washers The instrument was mounted on a support before an opening in a brass screen placed in front of the pile. The source of heat employed was spiral of platinum wire raised to incandescence by an electric current the spiral being enclosed in a small glass globe with an aperture in front through which the radiation passed unchanged in its character, a point essential importance overlooked by Melloni. The following contains the results of experiments made with liquids in the thicknesses indicated, the numbers expressing the *absorption* per cent.

al radiation. The *transmission* per cent. can be found in each y subtracting the absorption from 100. Thus a layer of water 0·2 iick absorbs 80·7 and transmits 19·3 per cent. of the radiation from iot spiral.

Absorption of heat by liquids.

Liquid	Thickness of liquid in parts of an inch				
	0·02	0·04	0·07	0·14	0·27
ılphide of carbon	5·5	8·4	12·5	15·2	17·3
oroform . .	16·6	25·0	35·0	40·0	44·8
ide of methyl .	36·1	46·5	53·2	65·2	68·6
ide of ethyl .	38·2	50·7	59·0	69·0	71·5
ızole . . .	43·4	55·7	62·5	71·5	73·6
ylene . . .	58·3	65·2	73·6	77·7	82·3
er . . .	63·3	73·5	76·1	78·6	85·2
etic ether . .	—	74·0	78·0	82·0	86·1
mic ether . .	65·2	76·3	79·0	84·0	87·0
ohol . . .	67·3	78·6	83·6	85·3	89·1
ter . . .	80·7	86·1	88·8	91·0	91·0

ppears from these tables, that there is no connection between dia-ancy and transparency. The liquids, except olive oil, are all colour-nd transparent, and yet vary as much as 75 per cent. in the amount it transmitted. Among the solids, smoky quartz, which is nearly e to light, transmits heat very well; while alum, which is perfectly ıarent, cuts off 88 per cent. of heat rays. As there are different es of transparency, so there are different degrees of diathermancy; ie one cannot be predicated from the other.

studying the transmission of heat from different parts of the spec-ıeparately, the connection between light and heat becomes manifest. this view Masson and Jamin received the spectrum of the solar given by a prism of rock salt on a movable screen provided with erture, so that by raising or lowering the screen the action of any part of the spectrum on different plates could be investigated. They ound—

at glass, rock crystal, ice, and generally substances transparent for are also diathermanous for all kinds of *luminous* heat;

ıt a coloured glass, red, for instance, which only transmits the red f the spectrum and extinguishes the others, also extinguishes every f luminous heat, excepting that of the red rays;

ıt glass and rock crystal, which are diathermanous for luminous also transmit the obscure heat near the red, that is, the most refran-but extinguish the extreme obscure rays, or those which are the leflected by the prism.

n extinguishes a still greater proportion of the obscure spectrum, e stops it altogether.

403. **Influence of the nature of the heat.**—The diathermanous pow differs greatly with the heat from different sources, as Melloni mad evident from the following table, in which the numbers express what pr portion of every ray 100 rays from the different sources of heat incider on the plates is transmitted :

	Locatelli's lamp	Incandescent platinum wire	Copper at 400°	Copper at 10
Rock salt . . .	92	92	92	92
Fluor spar . . .	78	69	42	33
Plate glass . . .	39	24	6	0
Black glass . . .	26	25	12	0
Selenite . . .	14	5	0	0
Alum	9	2	0	0
Ice	6	0·5	0	0

These different sources of heat correspond to light from different sources. Rock salt is here stated to transmit all kinds of heat with equal facility, and to be the only substance which does so. It is analogous to white glass, which is transparent for light from all sources. Fluor spar transmits 78 per cent. of the rays from a lamp, but only 33 of those from a blackened surface at 100°. A piece of plate glass only one-tenth of an inch thick and perfectly transparent to light, is opaque to all the radiation from a source of 100°, transmits only 6 per cent. of the heat from a source at 400°, and but 39 of the radiation from the lamp. Black glass, on the contrary, though it cuts off all heat from a source at 100°, allows 12 per cent. of the heat at 400° to pass, and is equally transparent to the heat from the spiral, but on account of its blackness is more opaque to the heat from the lamp. As we have already seen, every luminous ray is a heat ray ; now as several of the substances in this table are pervious to all the luminous rays, and yet, as in the case of ice, transmit but 6 per cent. of luminous heat, we have an apparent anomaly ; which, however, is only a confirmation of the remarkably small proportion which the luminous rays of a lamp bear to the obscure.

From these experiments Melloni concluded that as the temperature of the source rose more heat was transmitted. This may be taken as a general law, which has been recently confirmed by some refined experiments of Prof. Tyndall. The platinum lamp, previously described, was used as the source, the temperature of which Prof. Tyndall was enabled to vary from a dark to a brilliant white heat, without disturbing in any way the position of the apparatus ; the gradations of temperature being obtained by a gradual augmentation of the strength of the electric current which heated the platinum spiral. Instead of liquids, vapours were chosen as the subject of experiment, and examined in a manner to be described subsequently ; the measurements are given in the following table :—

Absorption of heat by vapours.

Name of vapour	Source, platinum spiral			
	Barely visible	Bright red	White hot	Near fusion
Bisulphide of carbon .	6·5	4·7	2·9	2·5
Chloroform . . .	9·1	6·3	5·6	3·9
Iodide of methyl . .	12·5	9·6	7·8	
Iodide of ethyl . .	21·3	17·7	12·8	
Benzole	26·4	20·6	16·5	
Amylene	35·8	27·5	22·7	
Ether	43·4	31·4	25·9	23·7
Formic ether . . .	45·2	31·9	25·1	21·3
Acetic ether . . .	49·6	34·6	27·2	

The percentage of rays absorbed is here seen to diminish in each case as the temperature of the source rises. Mere elevation of temperature does not, however, invariably produce a high penetrative power in the rays emitted; for Prof. Tyndall has shown that the rays from sources of far higher temperature than any of the foregoing are more largely absorbed by certain substances than are the rays emitted from any one of the sources as yet mentioned. Thus it was found that the radiation from a hydrogen flame was completely intercepted by a layer of water only 0·27 of an inch thick, the same layer transmitting 9 per cent. of the radiation from the red-hot spiral, a source of much lower temperature. The explanation of this is, that those rays which heated water emits (and water, the product of combustion, is the main radiant in a hydrogen flame) are the very ones which this substance most largely absorbs. This statement, which will become clearer after reading the analogous phenomena in the case of light, was strikingly exemplified by the powerful absorption of the heat from a carbonic oxide flame by carbonic acid gas. It will be seen presently (406) that of the rays from a heated plate of copper olefiant gas absorbs 10 times the quantity intercepted by carbonic acid, whilst of the rays from a carbonic oxide flame Prof. Tyndall found carbonic acid absorbed twice as much as olefiant gas. A tenth of an atmosphere of carbonic acid enclosed in a tube 4 feet long, absorbs 60 per cent. of the radiation from a carbonic oxide flame. Radiant heat of this character can thus be used as a delicate test for the presence of carbonic acid, the amount of which can even be accurately measured by the same means. This has been done by Mr. Barrett, who, in this way, has made a *physical* analysis of the human breath. In one experiment the quantity of carbonic acid contained in breath physically analysed was found to be 4·56 per cent., st the same breath chemically analysed gave 4·66, a difference of one-tenth per cent.

4. **Influence of the thickness and nature of screens.**—It will be n from the table (403) that of every 100 rays rock salt transmits 92. e other 8 may either have been absorbed or reflected from the surface

of the plate. According to Melloni, the latter is the case; for if, instead of on one plate, heat be allowed to fall on two or more plates whose total thickness does not exceed that of the one, the quantity of heat arrested will be proportional to the number of reflecting surfaces. He therefore concluded rock salt to be quite diathermanous.

The experiments of MM. Provostaye and Desains, of Mr. Balfour Stewart, and those of Prof. Tyndall, show that this conclusion is not strictly correct; rock salt does absorb a very small proportion of obscure rays.

The quantity of heat transmitted through rock salt is practically the same, whether the plate be 1, 2, or 4 millimeters thick. But with other bodies absorption increases with the thickness, although by no means in direct proportion. This is seen to be the case in the table of absorption by liquids at different thicknesses. The following table tells what proportion of 1,000 rays from a Locatelli's lamp pass through a glass plate of the given thickness :—

Thickness in millimeters .	0·5	1	2	3	4	5	6	7	8
Rays transmitted . .	775	733	682	653	634	620	609	600	592

The absorption takes place in the first layers; the rays which have passed these possess the property of passing through other layers in a higher degree, so that beyond the first layers the heat transmitted approaches a certain constant value. If a thin glass plate be placed behind another glass plate a centimeter thick, the former diminishes the transmission by little more than the reflection from its surface. But if a plate of alum were placed behind the glass plate, the result would be different, for the latter is opaque for much of the heat transmitted by glass.

Heat, therefore, which has traversed a glass plate traverses another plate of the same material with very slight loss, but is very greatly diminished by a plate of alum. Of 100 rays which had passed through green glass or tourmaline, only 5 and 7 were respectively transmitted by the same plate of alum. A plate of blackened rock salt only transmits obscure rays, while alum extinguishes them. Consequently, when these two substances are superposed, a system impervious to light and heat is obtained.

These phenomena find their exact analogies in the case of light. The different sources of heat correspond to flames of different colours, and the various screens to glasses of different colours. A red flame looked at through a red glass appears quite bright, but through a green glass it appears dim or is scarcely visible. So in like manner heat which has traversed a red glass passes through another red glass with little diminution, but it is almost completely stopped by a green glass. Rock salt at 150° emits only one kind of heat; it is monothermal just as sodium vapour is monochromatic.

Different luminous rays being distinguished by their *colours*, to these different obscure calorific rays Melloni gave the name of *thermocrose* or heat colouration. The invisible portion of the spectrum is accordingly apped out into a series of spaces, each possessing its own peculiar ature, corresponding to the coloured spaces which are seen in that rtion of the spectrum visible to our eyes.

Besides thickness and colour, the polish of a substance influences the ansmission. Glass plates of the same size and thickness transmit more at as their surface is more polished. Bodies which transmit heat of y kind very readily are not heated. Thus a window pane is not much ated by the strongest sun's heat; but a glass screen held before a mmon fire stops most of the heat, and is itself heated thereby. The ason of this is that by far the greater part of the heat from a fire is scure, and to this kind of heat glass is opaque.

405. **Diffusion of heat.**—When a ray of light falls upon an unpolished rface in a definite direction, it is decomposed into a variety of rays hich are reflected from the surface in all directions. This irregular re- ction is called *diffusion*, and it is in virtue of it that bodies are visible hen light falls upon them. A further peculiarity is, that all solar rays e not equally diffused from the surface of bodies. Certain bodies diffuse rtain rays and absorb others, and accordingly appear coloured. The d colour of a geranium is caused by its absorbing all the rays, excepting e red, which are irregularly reflected. Just as is the case with trans- itted light in transparent bodies, so with diffused light in opaque ones, r if a red body is illuminated by red light it appears of a bright red olour, but if green light fall upon it it is almost black. We shall now e that here again analogous phenomena prevail with heat.

Various substances diffuse different thermal rays to a different extent; ch possesses a peculiar thermocrose or heat tint. Melloni placed a umber of strips of brass foil between the source of heat and the thermo- ile. They were coated on the side opposite to the pile with lampblack, nd on the other side with the substances to be investigated. Represent- g the quantity of heat absorbed by the lampblack at 100, the absorption f the other bodies was as follows :—

	Incandescent platinum	Copper at 400°	Copper at 100°
Lampblack . . .	100	100	100
White lead . . .	56	89	100
Isinglass . . .	54	64	91
Indian ink . . .	95	87	85
Shellac . . .	47	70	72
Polished metal . .	13·5	13	13

Hence, white lead absorbs far less of the heat radiated from incan- lescent platinum than lampblack, but it absorbs the obscure rays from opper at 100° as completely as lampblack. Indian ink is the reverse of his; it absorbs obscure rays less completely than luminous rays. Lamp- lack absorbed the heat from all sources in equal quantities, and very early completely. In consequence of this property all thermoscopes hich are used for investigating radiant heat are covered with lamp- lack, as it is the best known absorbent of heat. The behaviour of metals is the reverse of that of lampblack. They reflect the heat of differe sources in the same degree. They are to heat what *white* bodies are light.

As coloured light is altered by diffusion from several bodies, so Kno lauch has shown that the different kinds of heat are altered by reflecti from different surfaces. The heat of an Argand lamp diffused fro white paper passes more easily through calcspar than when it has bee diffused from black paper.

The rays of heat, like the rays of light, are susceptible of polarisati and double refraction. These properties will be better understood aft treating of light.

406. **Relation of gases and vapours to radiant heat.**—For a lon time it was believed that gaseous bodies were as permeable to heat as vacuum; and though subsequently this was disproved, yet down to recent period it was thought that whatever absorption such bodies migh exercise was slight and similar in degree. The whole subject has, however, been investigated by Prof. Tyndall in a series of laborious experiments, which, with regard to the absorption of heat by gases, are of equal importance to those of Leslie, and afterwards of Melloni, in reference to solids and liquids.

The apparatus used in these experiments is represented, in its essentia features, in the adjacent figure; the arrangement being looked upon fro above.

A is a cylinder about 4 feet in length and 2½ inches in diameter, place horizontally, the ends of which can be closed with rock salt plates: b means of a lateral tube at *r* it can be connected with an air pump an exhausted; while at *t* is another tube which serves for the introduction o gases and vapours. T is a sensitive thermo-pile connected with a extremely delicate galvanometer M.

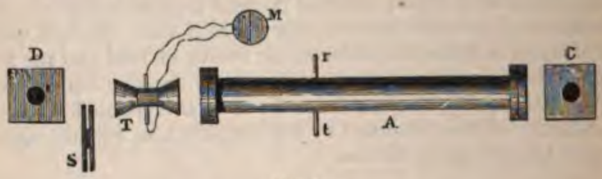


Fig. 315.

The deflections of this galvanometer were proportional to the degree of heat up to about 30°; beyond this point the proportionality no longe held good, and accordingly for the higher degrees a table was empiricall constructed, in which the value of the higher deflections was expresse in units; the unit being the amount of heat necessary to move the needl through one of the lower degrees.

C is a source of heat, which usually was either a Leslie's cube fille with boiling water, or else a sheet of blackened copper heated by gas Now when the source of heat was permitted to radiate through the exhausted tube, it caused the needle to assume a very high deflection; an ition a very considerable degree of absorption would have been produce an alteration of 1° of the galvanometer. And if to deflection a lower source of heat had been used, the fraction would be correspondingly less, and might well have been in- Hence Prof. Tyndall adopted the following device, by which he ed to use a powerful flux of heat, and at the same time dis- ll variations in the quantity falling on the pile.

rce of heat at C was allowed to radiate through the tube at the ch the pile was placed ; a deflection was produced of, say 70° ; source of heat, D, was then placed near the other face of the mount of heat falling on the pile from this *compensating* cube ılated by means of a movable screen S. When both faces of re warmed, two currents are produced, which are in opposite and tending therefore to neutralise each other : when the heat ces is precisely equal the neutralisation is perfect, and no current roduced, however high may be the temperature on both sides. angement just described, by means of the screen S, the radia- the compensating cube was caused to neutralise exactly the rom the source C ; the needle consequently was brought down o zero, and remained there so long as both sources were equal. as or vapour be admitted into the exhausted tube, any power of it may possess will be indicated by the destruction of this n, and preponderance of the radiation from the compensating ın amount corresponding to the heat cut off by the gas. Ex- this way, air, hydrogen, and nitrogen, when dried by passing ılphuric acid, were found to exert an almost inappreciable effect ; ence as regards radiant heat being but little different to a But with olefiant and other complex gases the case was entirely Representing by the number 1 the quantity of radiant heat by air, olefiant gas absorbs 970 times, and ammoniacal gas 1195 amount. In the following table is given the absorption of eat by various gases, referred to air as unity :—

ıe of gas	Absorption under 30 inches pressure
	1
ygen	1
rogen	1
drogen	1
lorine	39
drochloric acid	62
rbonic acid	90
rous oxide	355
rsh gas	403
phurous acid	710
fiant gas	970
ımonia	1195

ad of comparing the gases at a common pressure of one atmo- ey are compared at a common pressure of an inch, their differences in absorption are still more strikingly seen. Thus assuming th absorption by 1 inch of dry air to be 1, the absorption by 1 inch of olefiar gas is 7,950, and by the same amount of sulphurous acid 8,800.

407. **Influence of pressure and thickness on the absorption heat by gases.**—The absorption of heat by gases varies with the pressure this variation cannot be seen in the case of air, as the total absorption i so small, but in the case of those gases which have considerable absor tive power it is easily shown. Taking the total absorption by atmo spheric air under ordinary pressure at unity, the numbers of olefiant ga under a pressure of 1, 3, 5, 7, and 10 inches of mercury are respectivel 90, 142, 168, 182, and 193. Thus one-thirtieth of an atmosphere olefiant gas exerts 90 times the absorption of an entire atmosphere of ai And the absorption, it is seen, increases with the density, though not i a direct ratio. Prof. Tyndall showed, however, by special experiment that for very low pressures the absorption does increase with the densit Employing as a unit volume of the gas a quantity which measured onl $\frac{1}{50}$th of a cubic inch, and admitting successive measures of olefiant gas int the experimental tube, it was found that up to 15 measures the absorptio was directly proportionate to the density in each case.

In these experiments the length of the experimental tube remained th same whilst the pressure of the gas within it was caused to vary; in othe subsequent experiments the pressure of the gas was kept constant, whil the length of the tube was, by suitable means, varied from 0·01 of an inc up to 50 inches. The source was a heated plate of copper; of the tot radiation from this nearly 2 per cent. were absorbed by a film of olefiar gas ·01 of an inch thick, upwards of 9 per cent. by a layer of the same ga 0·1 of an inch thick, 33 per cent. by a layer 2 inches thick, 68 per cen by a column 20 inches long, and 77 per cent. by a column rather mor than 4 feet long.

408. **Absorptive power of vapours.**—Great as is the absorptiv power of olefiant gas, it is exceeded, as Prof. Tyndall found, by that several vapours. The mode of experimenting was analogous to that wit the gases. The liquid from which the vapours were to be derived wa enclosed in a small flask, which could be attached with a stopcock to th exhausted experimental tube. The absorption was then determined afte admitting the vapours into the tube in quantities measured by the pressur of the barometer gauge attached to the air pump.

The following table shows the absorption of vapours under pressure varying from 0·1 to 1·0 inch of mercury:—

Name of vapours	Absorption under pressure in inches of mercury		
	0·1	0·5	1·0
Bisulphide of carbon	15	47	62
Benzole	66	182	267
Chloroform	85	182	236
Ether	300	710	870
Alcohol	325	622	
Acetic ether	590	980	1195

These numbers refer to the absorption of a whole atmosphere of dry ir as their unit, and it is thus seen that a quantity of bisulphide of car- on vapour, the feeblest absorbent yet examined, which only exerts a ressure of $\frac{1}{10}$th of an inch of mercury, or the $\frac{1}{300}$th of an atmosphere, gave 5 times the absorption of an entire atmosphere of air; and $\frac{1}{10}$th of an inch f acetic ether 590 times as much. Comparing air at a pressure of 0·1 ith acetic ether of the same pressure, the absorption of the latter would e more than 17,500 times as great as that of the former.

The absorption by the infinitesimally small quantity of matter consti- uting a perfume can never be measured; for Prof. Tyndall found that he odours from the essential oils exercised a marked influence on radiant eat. Perfectly dry air was allowed to pass through a tube containing ried paper impregnated with various essential oils, and then admitted nto the experimental tube. Taking the absorption of dry air as unity, he following were the numbers respectively obtained for air scented with arious oils :—Patchouli 31, otto of roses 37, lavender 60, thyme 68, rose- ary 74, cassia 109, aniseed 372. Thus the perfume of a flower-bed bsorbs a large percentage of the heat of low refrangibility emitted from it.

Ozone prepared by electrolysing water was also found to have a re- arkable absorptive effect. The small quantity of ozone present in elec- olytic oxygen was found in one experiment to exercise 136 times the bsorption of the entire mass of the oxygen itself.

But the most important results which Prof. Tyndall has obtained are hose which follow from his experiments on the behaviour of aqueous apour to radiant heat. The experimental tube was filled with air, dried s perfectly as possible, and the absorption it exercised was found to be ne unit. Exhausting the tube, and admitting the ordinary undried, but ot specially moist, air from the laboratory, the absorption now rose to 2 units. This difference between dried and undried air can only be scribed to the aqueous vapour the latter contains. Thus on a day of verage humidity the absorptive effect due to the transparent aqueous apour present in the atmosphere is 72 times as great as that of the air self, though in quantity the latter is about 200 times greater than the ormer. Analogous results were obtained on different days, and with pecimens of air taken from various localities. When air which had een specially purified was allowed to pass through a tube filled with ragments of moistened glass and examined, it was found to exert an bsorption 90 times that of pure air.

In some other experiments Prof. Tyndall suppressed the use of rock alt plates in his experimental tube, and even the tube itself, and yet in very case the results were such as to show the great power which aqueous apour possesses as an absorbent of radiant heat.

The absorptive action which the aqueous vapour in the atmosphere xerts on the sun's heat has been established by a series of actinometrical bservations made by Soret at Geneva and on the summit of Mont lanc; he finds that the intensity of the solar heat on the top of Mont lanc is $\frac{4}{5}$ths of that at Geneva; in other words, that of the heat which is diated at the height of Mont Blanc, about $\frac{1}{5}$th is absorbed in passing through a vertical layer of the atmosphere 14,436 feet in thickness. The same observer has found that with virtually equal solar heights there is the smallest transmission of heat on those days on which the tension of aqueous vapour is greatest, that is, when there is most moisture in the atmosphere.

409. **Radiating power of gases.**—Prof. Tyndall also examined the *radiating* power of gases. A red-hot copper ball was placed so that the current of heated air which rose from it acted on one face of a thermopile; this action was compensated by a cube of hot water placed in front of the opposite face. On then allowing a current of dry olefiant gas from a gasholder to stream through a ring burner over the heated ball and thus supplant the ascending current of hot air, it was found that the gas radiated energetically. By comparing in this manner the action of many gases it was discovered that, as is the case with solids, those gases which are the best absorbers are also those which radiate most freely.

410. **Dynamic radiation and absorption.**—To another class of phenomena which Prof. Tyndall discovered he gives the name, *dynamic radiation and absorption.*

A gas when permitted to enter an exhausted tube is heated in consequence of the collision of its particles against the sides of the vessel; it thus becomes a source of heat, which is perfectly capable of being measured. Prof. Tyndall calls this *dynamic heating.* In like manner, when a tube full of gas or vapour is rapidly exhausted, a chilling takes place owing to the loss of heat in the production of motion. This Prof. Tyndall calls *dynamic chilling or absorption.*

He could thus determine the radiation or absorption of a gas without any source of heat external to the gas itself. An experimental tube was taken, one end of which was closed with a polished metal plate, and the other with a plate of rock salt; in front of the latter was the face of the pile. The needle being at zero, and the tube exhausted, a gas was allowed quickly to enter until the tube was full, the effect on the galvanometer being noted. This being only a transitory effect the needle soon returned to zero; the tube was then rapidly pumped out, by which a sudden chilling was produced, and the needle exhibited a deflection in the opposite direction.

Comparing in this way the dynamic heating and chilling of various gases, it was found that those gases which are the best absorbers are in like manner the best radiators.

Metallic surfaces when polished are, as we have seen (393), bad radiators, but radiate freely when covered with varnish. Now Prof. Tyndall made the curious experiment of varnishing a metallic surface by a film o gas. A Leslie's cube was placed with its polished metal side in front o the pile, and its effect neutralised by a second cube placed before the other face of the pile. On allowing, by a special arrangement, a stream of olefiant or coal gas to flow from a gasholder over the metallic face o the first cube, a copious radiation from that side was produced as long a the flow of gas continued. Acting on the principle indicated in the foregoing xperiment, Prof. Tyndall determined the dynamic radiation and absorp-ion of vapours. The experimental tube containing a vapour under a mall known pressure, air was allowed to enter until the pressure inside he tube was the same as that of the atmosphere. In this way the ntering air by its impact against the tube became heated; and its articles mixing with those of the minute quantity of vapour present, each f them became, so to speak, coated with a layer of the vapour. The ntering air was in this case a source of heat, just as in the above experi-ents the Leslie cube was. Here, however, one gas varnished another: he radiation and subsequently the absorption of various vapours could hus be determined.

It was found that vapours differed very materially in their power of adiating under these circumstances: of those which were tried bisul-hide of carbon vapour was the worst and boracic ether the best radiator. And in all cases those which were the best absorbents were also the best adiators. By this method Prof. Tyndall was able to observe a definite adiative power with the more powerful vapours when the quantity present as immeasurably small.

411. **Relation of absorption to molecular state.**—Up to a recent eriod it was considered that the absorption of heat was mainly dependent pon the physical condition of the body examined. This led to the elief that it was impossible for substances of such tenuity as gases and apours to absorb any sensible amount of heat; and that the absorption y bodies when in a liquid state would be unlike the same bodies when olid; moreover, that if all solid bodies were reduced to an equally fine tate of division, the present differences in their absorbent and radiative owers would disappear. A few experiments made by Melloni on tmospheric air supported the first idea, and a series of experiments by asson and Courtepée established the belief in the last. But we have een that Prof. Tyndall's researches have revealed the powerful absorption f heat by various gases and vapours, and we shall now briefly show that he researches of the same philosopher have overthrown the last two onclusions, giving us an insight into the cause of the absorption of heat hich before was unattainable.

After the examination of the absorption of heat by vapours, Prof. Tyndall tried the same substances in a liquid form. The conditions of he experiments were in both cases the same; the source of heat was lways a spiral of platinum, heated to redness by an electric current of nown strength; and plates of rock salt were invariably employed to ontain both vapours and liquids. Finally, the absorption by the vapours as remeasured; in this case introducing into the experimental tube, not s before equal quantities of vapour, but amounts proportional to the ensity of the liquid. When this last condition had been attained, it as found thar the order of absorption by a series of liquids, and by the ame series when turned into vapour, was precisely the same. Thus the bstances tried stood in the following order as liquid and as vapour, be-nning with the feeblest absorbent, and ending with the most powerful:—

Liquids	Vapours
Bisulphide of carbon	Bisulphide of carbon.
Chloroform	Chloroform.
Iodide of methyl	Iodide of methyl.
Iodide of ethyl	Iodide of ethyl.
Benzole	Benzole.
Amylene	Amylene.
Sulphuric ether	Sulphuric ether.
Acetic ether	Acetic ether.
Formic ether	Formic ether.
Alcohol	Alcohol.
Water.	

A direct determination of the proportional amount of the vapou water could not be made, on account of the lowness of its tension, the hygroscopic nature of the plates of the rock salt. But the remark and undeviating regularity of the absorption by all the other substa in the list, when as liquid and vapour, establishes the fact, which is roborated by the experiments we have already mentioned, that aqu vapour is one of the most energetic absorbents of heat.

In this table it will be noticed that those substances which have simplest chemical constitution stand first in the list, with one anoma exception, namely, that of water. In the absorption of heat by gases, Tyndall found that the elementary gases were the feeblest absorb while the gases of most complex constitution were the most pow absorbers. These facts, which were found in a general way to be tru solids, liquids, and gases, have led Prof. Tyndall to infer that absorp is mainly dependent on chemical constitution ; that is to say, that sorption and radiation are molecular acts independent of the physical dition of the body.

But this conclusion appeared to be contradicted by the experimen Masson and Courtepée on powders. Prof. Tyndall has therefore repe these experiments, and found them to be entirely incorrect. Avoi the source of error into which the French experimenters had fa Tyndall has discovered that the radiation of powders is similar to th the solids from which they were derived, and therefore differs gr *inter se.* The absorbent power of powders was also found to corresp with their radiative power—as we have shown to be the case with s and gases, and, though as yet we have no experiments on the subjec doubtless also true for liquids. The powders were attached to th surfaces of a Leslie's cube, in such a manner that radiation took p from the surface of the powder alone. The following table gives radiation in units from some of the powders examined by Tyndall; metal surface of the cube giving a deflection of 15 units :—

Radiation from powders.

Rock salt	35·3	Chloride of lead	
Biniodide of mercury	39·7	Carbonate of calcium	
Sulphur	40·6	Red oxide of lead	

Radiation from powders—continued.

lphate of calcium	77·7	Black oxide of iron	81·3
d oxide of iron	78·4	Sulphide of iron	81·7
ydrated oxide of zinc	80·4	Lampblack	84·0

It will be noticed that these substances are of various colours. Some e white, such as rock salt, chloride of lead, carbonate and sulphate of lcium, and hydrated oxide of zinc; some are red, such as biniodide of ercury and oxide of lead; whilst others are black, as sulphide of iron d lampblack: we have besides other colours. The colours therefore ve no influence on the radiating power: for example, rock salt is the eblest radiator, and hydrated oxide of zinc one of the most powerful diators. The views of Prof. Tyndall therefore, instead of being overrown, were confirmed by these his latest experiments.

Nearly a century ago Franklin made experiments on coloured pieces f cloth, and found their absorption, indicated by their sinking into snow n which they were placed, to increase with the darkness of the colour. But all the cloths were equally powerful absorbents of obscure heat, and he effects noticed were only produced by their relative absorptions of ght. In fact, the conclusions to be drawn from Franklin's experiment nly holds good for luminous heat, especially sunlight, such as he emloyed.

412. **Applications.**—The property which bodies possess of absorbing, mitting, and reflecting heat, meets with numerous applications in domestic conomy and in the arts. Leslie stated in a general manner that white odies reflect heat very well, and absorb very little, and that the contrary s the case with black substances. As we have seen, this principle is not enerally true, as Leslie supposed; for example, for non-luminous rays hite lead has as great an absorbing power as lampblack (405). Leslie's rinciple applies to powerful absorbents like cloth, cotton, wool and other rganic substances when exposed to luminous heat. Accordingly, the ost suitable coloured clothing for summer is just that which experience as taught us to use, namely, white, for it absorbs less of the sun's rays han black clothing, and hence feels cooler.

The polished fire-irons before a fire are cold, whilst the black fender s often unbearably hot. If, on the contrary, a liquid is to be kept hot s long as possible, it must be placed in a brightly polished metallic essel, for then, the emissive power being less, the cooling is slower. It s for this reason advantageous that the steam pipes, etc., of locomotives hould be kept bright.

In the Alps, the mountaineers accelerate the fusion of the snow by overing it with earth, which increases the absorbing power.

In our dwellings, the outsides of the stoves and of hot-water apparatus ught to be black, and the insides of fire-places ought to be lined with re-clay, in order to increase the radiating power towards the apartment.

It is in consequence of the great diathermaneity of dry atmospheric r that the higher regions of the atmosphere are so cold, notwithstanding the great heat which traverses them : whilst the intense heat of the sun's direct rays on high mountains is probably due to the comparative absence of aqueous vapour at those high elevations.

As nearly all the luminous rays of the sun pass through water, and the sun's radiation as we receive it on the surface of the earth consisting of a large proportion of luminous rays, accidents have often arisen from the convergence of these luminous rays by bottles of water which act as lenses. In this way gunpowder could be fired by the heat of the sun's rays concentrated by a water lens; and the drops of water on leaves in greenhouses have, it is said, been found to act as lenses, and burn the leaves on which they rest.

Certain bodies can be used (402), to separate the heat and light radiated from the same source. Rock salt covered with lampblack, or still better with iodine, transmits heat, but completely stops light. On the other hand, alum, either as a plate or in solution, or a thin layer of water, is permeable to light, but stops all the heat from obscure sources. This property is made use of in apparatus which are illuminated by the sun's rays, in order to sift the rays of their heating power, and a vessel full of water or a solution of alum is used with the electric light when it is desirable to avoid too intense a heat.

In gardens, the use of shades to protect plants depends partly on the diathermancy of glass for heat from luminous rays and its athermancy for obscure rays. The heat which radiates from the sun is largely of the former quality, but by contact with the earth it is changed into obscure heat, which as such cannot retraverse the glass. This explains the manner in which greenhouses accumulate their warmth, and also the great heat experienced in summer in rooms having glass roofs, for the glass in both cases effectually entraps the solar rays. On the same principle plates of glass are frequently used as screens to protect us from the heat of a fire : the glass allows us to see the cheerful light of the fire, but intercepts the larger part of the heat radiated from the fire. Though the screens thus become warm by the heat they have absorbed, yet as they radiate this heat in all directions, towards the fire as well as towards us, we finally receive less heat when they are interposed.

CHAPTER IX.

CALORIMETRY.

413. **Calorimetry. Thermal unit.**—The object of calorimetry is to measure the *quantity of heat* which a body parts with or absorbs when its temperature sinks or rises through a certain number of degrees, or when it changes its condition.

Quantities of heat may be expressed by any of its directly measurable effects, but the most convenient is the alteration of temperature, and quantities of heat are usually defined by stating the extent to which they able of raising a known weight of a known substance, such as

unit chosen for comparison, and called the *thermal unit*, is not iere the same. In France it is the quantity of heat necessary to ie temperature of *one* kilogramme of water through *one* degree ade ; this is called a *calorie*. In this book we shall adopt, as a unit, *the quantity of heat necessary to raise one pound of water one degree Centigrade* : 1 *calorie* = 2·2 thermal units, and 1 thert = 0·45 *calorie*.

Specific heat.—When equal weights of two different substances same temperature placed in similar vessels are subjected for the ength of time to the heat of the same lamp, or are placed at the istance in front of the same fire, it is found that their temperatures y considerably ; the mercury will be much hotter than the water. from the conditions of the experiment, they have each been rethe same amount of heat, it is clear that the quantity of heat s sufficient to raise the temperature of mercury through a certain of degrees will only raise the temperature of the same quantity r through a less number of degrees; in other words, that it remore heat to raise the temperature of water through one degree does to raise the temperature of mercury by the same extent. sely, if the same quantities of water and of mercury at 100° C. be to cool down to the temperature of the atmosphere, the water will a much longer time for the purpose than the mercury : hence, in through the same number of degrees, water gives out more heat oes mercury.

readily seen that all bodies have not the same specific heat. If a of mercury at 100° is mixed with a pound of water at zero, the ature of the mixture will only be about 3°. That is to say, that he mercury has cooled through 97°, the temperature of the water ly been raised 3°. Consequently the same weight of water requires 32 times as much heat as mercury does to produce the same elevatemperature.

milar experiments are made with other substances it will be found e quantity of heat required to effect a certain change of temperadifferent for almost every substance, and we speak of the *specific calorific capacity* of a body as the quantity of heat which it absorbs ts temperature rises through a given range of temperature, from 1° for example, compared with the quantity of heat which would orbed under the same circumstances, by the same weight of water. er words, water is taken as the standard for the comparison of heats. Thus, to say that the specific heat of lead is 0·0314, that the quantity of heat which would raise the temperature of ven quantity of lead through 1° C. would only raise the temperature same quantity of water through 0·0314.

perature is the *vis viva* of the smallest particles of a body ; in of the same temperature the atoms have the same *vis viva*, the r mass of the lighter atoms being compensated by their greater velocity. The heat absorbed by a body not only raises its temperatu that is increases the *vis viva* of the progressive motion of the atoms, in overcoming the attraction of the atoms it moves them further apart, along with the expansion which this represents some external pressure overcome. In the conception of specific heat is included, not merely th amount of heat which goes to raise the temperature, but also that necessar for the internal work of expansion, and that required for the external wor If these latter could be separated we should get the true *heat of tempera ture*, that which is solely used in increasing the *vis viva* of the atoms. Th is sometimes called the *true specific heat*.

Three methods have been employed for determining the specific hea of bodies: (i.) the method of the melting of ice, (ii.) the method mixtures, and (iii.) that of cooling. In the latter, the specific heat of body is determined by the time which it takes to cool through a certai temperature. Previous to describing these methods, it will be convenien to explain the expression for the quantity of heat absorbed or given by a body of known weight and specific heat, when its temperature ri or falls through a certain number of degrees.

415. **Measure of the sensible heat absorbed by a body.**—Let *m* b the weight of a body in pounds, *c* its specific heat, and *t* its temperatur The quantity of heat necessary to raise a pound of water through degree being taken as unity, *m* of these units would be required to rai *m* pounds of water through one degree, and to raise it through *t* degree *t* times as much, or *mt*. As this is the quantity of heat necessary to ra through *t* degrees *m* pounds of water whose specific heat is unity, a bo of the same weight only of different specific heat, would require *m* Consequently, when a body is heated through *t* degrees, the quantity heat which it absorbs is *the product of its weight into its temperatu into its specific heat*. This principle is the basis of all the formulæ f calculating specific heats.

If a body is heated or cooled from t' to t degrees, the heat absorbed disengaged will be represented by the formula

$$m(t'-t)c, \text{ or } m(t-t')c.$$

416. **Method of the fusion of ice.**—This method of determini specific heats is based on the fact that melt a pound of ice 80 thermal units necessary, or more exactly 79·25. Black calorimeter (fig. 316) consists of a bl of ice in which a cavity is made, which is provided with a cover of The substance whose specific heat is be determined is heated to a certain te perature, and then placed in the cav which is covered. After some time body becomes cooled to zero. It is th opened, and both the substance and the cavity wiped dry with a sp which has been previously weighed. The increase of weight of th

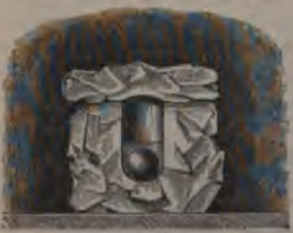


Fig. 316.

t obviously represents the ice which has been converted into r, since one pound of ice at 0° in melting to water at 0° absorbs rmal units, P pounds absorbs 80 P units. On the other hand, this ty of heat is equal to the heat given out by the body in cooling t° to zero, which is *mtc*, for it may be taken for granted that in g from t° to zero a body gives out as much heat as it absorbs in heated from zero to t°. Consequently, from

$$mtc = 80\ \text{P we have } c = \frac{80\text{P}}{mt}.$$

difficult to obtain blocks of ice as large and pure as those used by in his experiments, and Lavoisier and Laplace have replaced the of ice by a more complicated apparatus, which is called the *ice meter*. Fig. 317 gives a perspective view of it, and fig. 318 repre- section. It consists of three concentric tin vessels; in the central placed the body M, whose specific heat is to be determined, while o others are filled with pounded ice. The ice in the compartment nelted by the heated body, while the ice in the compartment B cuts heating influence of the surrounding atmosphere. The two stop- E and D give issue to the water which arises from the liquefaction ice.

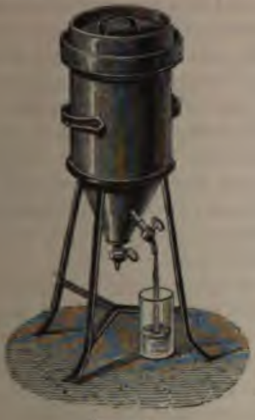


Fig. 317.

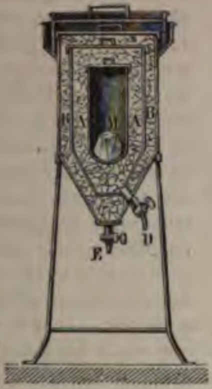


Fig. 318.

order to find the specific heat of a body by this apparatus, its t *m* is first determined; it is then raised to a given temperature, *t*, eping it for some time in an oil or water bath, or in a current of . Having been quickly brought into the central compartment, the e replaced and covered with ice, as represented in the figure. The which flows out by the stopcock D is collected. Its weight, P, is estly that of the melted ice. The calculation is then made as in the ding case.

There are many objections to the use of this apparatus. From it requires some quantity of ice, and a body, M, of large mass; wl experiment lasts a considerable time. A certain weight of the water remains adhering to the ice, so that the water which flows o D does not exactly represent the weight of the melted ice.

417. **Bunsen's Ice Calorimeter.**—On the very considerable dim of volume which ice experiences on passing into water (320), Buns based a calorimeter which is particularly suited only small quantities of a substance can be u determinations. A small test tube *a* (fig. 319) inter receive the substance experimented upon is fused wider tube B. The part *ab* contains pure freshly out distilled water, and the prolongation of this tu together with the capillary tube *d*, contains pure m This tube *d* is firmly fixed to the end of the tube C graduated, and the value of each division of the g tion is specially determined by calibration. Wh apparatus is immersed in a freezing mixture, the w the part freezes. Hence, if afterwards while the app is protected against the access of heat from with weighed quantity of a substance at a given temp be introduced into the tube, it imparts its heat to sinking to zero. In doing so it melts a certain q of ice which is evidenced by a corresponding dep of the mercury in tube *d*. Thus the weight of ice together with the weight and original temperature substance experimented upon, furnish all the da calculating the specific heat.

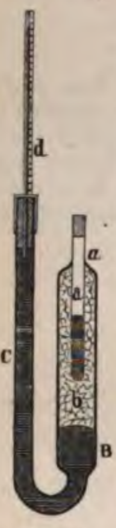


Fig. 319.

For this mode of determining the specific heat determination of the latent heat of ice was mad was found to be 80·025. It was also in connection with these ments that Bunsen made his determination of the specific gravity which he found to be in the mean 0·91674.

By the above method Bunsen determined the specific heat of of the rare metals for which a weight of only a few grains could be

418. **Method of mixtures.**—In determining the specific hea solid body by this method, it is weighed and raised to a known te ture, by keeping it, for instance, for some time in a closed space by steam; it is then immersed in a mass of cold water, the weig temperature of which are known. From the temperature of the after mixture the specific heat of the body is determined.

Let M be the weight of the body, T its temperature, c its specific and let m be the weight of the cold water, and t its temperature.

As soon as the heated body is plunged into the water, the temp of the latter rises until both are at the same temperature. Let th perature be θ. The heated body has been cooled by $T-\theta$; it has, fore, lost a quantity of heat, $M(T=\theta)c$. The cooling water has, contrary, absorbed a quantity of heat equal to $m(\theta-t)$, for the s

f water is unity. Now the quantity of heat given by the body
ifestly equal to the quantity of heat absorbed by the water; that is,
$-t)c=m(\theta-t)$, from which

$$c=\frac{m(\theta-t)}{M(T-t)}.$$

example will illustrate the application of this formula. A piece of
eighing 60 ounces, and at a temperature of 100° C., is immersed in
nces of water, whose temperature is 19° C. After the temperatures
become uniform, that of the cooling water is found to be 22° C.
is the specific heat of the iron?

e the weight of the heated body M is 60, the temperature T is 100°,
be determined; the temperature of mixture, t', is 22°, the weight of
oling water is 180, and its temperature 19°. Therefore

$$c=\frac{180(22-19)}{60(100-22)}=\frac{9}{78}=0{\cdot}1153.$$

Corrections.—The vessel containing the cooling water is usually
l cylinder of silver or brass, with thin polished sides, and is sup-
by some badly-conducting arrangement. It is obvious that this
which is originally at the temperature of the cooling water, shares
rease of temperature, and in accurate experiments this must be
d for. The decrease of temperature of the heated body is equal to
crease of temperature of the cooling water, and of the vessel in
it is contained. If the weight of this latter be m', and its specific
', its temperature, like that of the water, is t: consequently, the
us equation becomes

$$Mc(T-t)=m(\theta-t)+m'c'(\theta-t);$$

hich, by obvious transformations,

$$c=\frac{(m+m'c')\ (\theta-t)}{M(T-t)}.$$

erally speaking, the value $m'\,c'$ is put $=\mu$; that is to say, μ is the
of water which would absorb the same quantity of heat as the
This is said to be the *reduced value* in water of the vessel, or the
equivalent. The expression accordingly becomes

$$c=\frac{(m+\mu)\ -t)}{M(T-t)}.$$

ccurate experiments it is necessary also to allow for the heat ab-
by the glass and mercury of the thermometer, by introducing into
ation their values reduced on this principle.

rder to allow for the loss of heat due to radiation, a preliminary
nent is made with the body whose specific heat is sought, the only
of which is to ascertain approximately the increase of temperature
cooling water. If this increase be 10°, for example, the tempera-
the water is reduced by half this number—that is to say 5° below
perature of the atmosphere—and the experiment is then carried
he ordinary manner.

By this method of compensation, first introduced by Rumford, t water receives as much heat from the atmosphere during the first part the experiment as it loses by radiation during the second part.

420. **Regnault's apparatus for determining specific heats.**—Fig. 3 represents one of the forms of apparatus used by M. Regnault in determi ing specific heats by the method of mixtures.

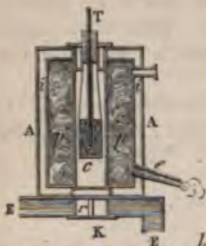


Fig. 321.

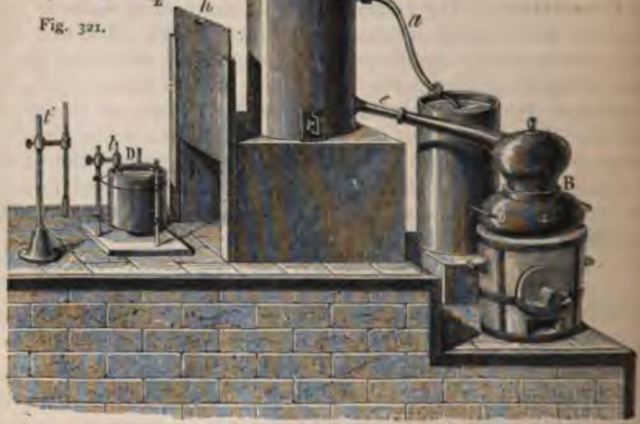


Fig. 320.

The principal part is a water-bath, AA, of which fig. 321 represents section. It consists of three concentric compartments; in the centr one there is a small basket of brass wire, *c*, containing fragments of t substance to be determined, in the middle of which is placed a therm meter, T. The second compartment is heated by a current of stea coming through the tube *e*, from a boiler, B, and passing into a worm, where it is condensed. The third compartment, *ii*, is an air chamber, hinder the loss of heat. The water bath AA rests on a chamber, with double sides, EE, forming a jacket, which is kept full of cold wat in order to exclude the heat from AA and from the boiler B. The centr compartment of the water bath is closed by a damper, *r*, which can opened at pleasure, so that the basket *c* can be lowered into the cha ber K.

he left of the figure is represented a small and very thin brass D, suspended by silk threads on a small carriage, which can be out of, or into, the chamber K. This vessel, which serves as a eter, contains water, in which is immersed a thermometer, t. r thermometer at the side, t', gives the temperature of the air.

n the thermometer T shows that the temperature of the substance bath is stationary, the screen h is raised, and the vessel D moved below the central compartment of the water bath. The damper r withdrawn, and the basket c and its contents are lowered into the f the vessel D, the thermometer T remaining fixed in the cork. rriage and the vessel D are then moved out, and the water agi- ntil the thermometer T becomes stationary. The temperature which ates is θ. This temperature known, the rest of the calculation is n the manner described in art. 419, care being taken to make all essary corrections.

etermining the specific heat of substances—phosphorus, for e—which could not be heated without causing them to melt, or o some change which would interfere with the accuracy of the Regnault adopted an inverse process; he cooled them down to a ature considerably below that of the water in the calorimeter, and bserved the diminution in the temperature of the latter, which d from immersing the cooled substance in it.

scertain the specific heat of bodies, such as potassium, where the water is quite inapplicable, the determination is made in another such as turpentine or benzole, the specific heat of which is known.

Method of cooling.—Equal weights of different bodies whose heats are different, will occupy different times in cooling through ne number of degrees. Dulong and Petit have applied this prin- determining the specific heats of bodies in the following manner: l polished silver vessel is filled with the substance in a state of fine , and a thermometer placed in the powder, which is pressed down. ssel is heated to a certain temperature, and is then introduced into er vessel, in which it fits hermetically. This copper vessel is ex- l, and maintained at the constant temperature of melting ice, and e noted which the substance takes in falling through a given range perature, from 15° to 5° for example. The times which equal s of different bodies require for cooling through the same range of ature are directly as their specific heats.

ault has proved that with solids this method does not give trust- results; it assumes, which is not quite the case, that the cooling arts is equal, and that all substances part with their heat to the ase with equal facility. The method may, however, be employed ccess in the determination of the specific heat of liquids.

Specific heat of liquids.—The specific heat of liquids may be ined either by the method of cooling, by that of mixtures, or by the ice calorimeter. In the latter case they are contained in a etal vessel, or a glass tube, which is placed in the central compart- ig. 318), and the experiment then made in the usual manner.

It will be seen from the following table that water and oil of turp have a much greater specific heat than that of other substances, and especially than the metals. It is from its great specific heat that requires a long time in being heated or cooled, and that for the weight and temperature it absorbs or gives out far more heat than substances. This double property is applied in the hot water appa of which we shall presently speak, and it plays a most important p the economy of nature.

423. **Mean specific heats of solids and liquids between 0° and** —By means of the method of mixture and of that of cooling, M. Re has determined the specific heats of a number of bodies. The foll table contains the numbers obtained for the bodies usually met with arts :—

Substances	Specific heats	Substances	S
Water	1·00000	Nickel	0·
Turpentine . . .	0·42590	Cobalt	0·
Calcined animal charcoal	0·26085	Zinc	0·
Wood charcoal . .	0·24111	Copper	0·
Sulphur	0·20259	Brass	0·
Graphite	0·20187	Silver	0·
Thermometer glass . .	0·19768	Tin	0·
Phosphorus . . .	0·18949	Antimony . . .	0·
Diamond . . .	0·14687	Mercury	0·
Grey iron . . .	0·12983	Gold	0·
Steel	0·11750	Platinum . . .	0·
Iron	0·11379	Bismuth	0·

These numbers represent the mean specific heats between 0° and Dulong and Petit's investigations have, however, shown that the sp heats increase with the temperature. Those of the metals, for ins are greater between 100° and 200° than between zero and 100°, a still greater between 200° and 300°. That is to say, a greater amo heat is required to raise a body from 200 to 250° than from 100° to and still more than from zero to 50°. For silver, the mean specific between 0° and 100° is 0·0557, while between 0° and 200° it is o The specific heat of platinum for any temperature may be express the formula $0{\cdot}0328 + 0{\cdot}0000042t$, where t is the temperature ; and of water by the formula $1 + 0{\cdot}00004t + 0{\cdot}0000009t^2$.

The increase of specific heat with the temperature is greater as b are nearer their fusing point. Any action which increases the d and molecular aggregation of a body, diminishes its specific heat. specific heat of copper is diminished by its being hammered, but it re its original value after the metal has been again heated.

The specific heat of a liquid increases with the temperature much rapidly than that of a solid. Water is, however, an exception ; its sp heat increases less rapidly than does that of solids.

A substance in the liquid state has a greater specific heat than w is solid ; thus, melted tin has the specific heat 0·0637, while that of ly 0·05623. The specific heat of liquid bromine is 0·111, that of omine being 0·081. The difference in the case of water is greater. ific heat is 1, that of ice, according to Person, being 0·504. In eous state a body has a higher specific heat than in the liquid

llet used the specific heat of platinum for measuring high degrees Supposing 200 ounces of platinum had been heated in a furnace, d then been placed in 1000 ounces of water, the temperature of it had raised from 13° to 20°. From the formula we have M = 200, o; θ is 20, and t is 13. The specific heat of platinum is 0·033, and e, therefore, from the equation,

$$Mc(T-\theta)=m(\theta-t)$$

$$T=\frac{m(\theta-t)+Mc\theta}{Mc}=\frac{7000+132}{6{\cdot}6}=\frac{7132}{6{\cdot}6}=1080^\circ.$$

found, however, that the specific heat of platinum at temperatures ut 1000° is 0·0373; if this value, therefore, be substituted for c in ove equation,

$$T=\frac{7152{\cdot}2}{7{\cdot}46}=958^\circ \text{ C.}$$

his method, which requires great skill in the experimenter, Pouillet ined a series of high temperatures. He found, for example, the rature of melting iron to be 1500° to 1600° C.

Dulong and Petit's law.—A knowledge of the specific heat of has become of great importance, in consequence of Dulong and discovery of the remarkable law, that the product of the specific f any element into its atomic weight is a constant number, a law may also be enunciated by saying that *the specific heats of simple are inversely as their atomic weights.* Thus, taking the atomic of iron at 28, its specific heat 0·11379, and the product 3·186; the weight of nickel is 29·5, its specific heat 0·10863, product 3·204; the weight of hydrogen is 1, its specific heat 3·2, and the product is 3·2. nault, who determined the specific heats of a large number of nts with great care, confirmed Dulong and Petit's law, but he found e number, instead of being constant, as Dulong and Petit had sup- varies between 2·95 and 3·41. These variations may depend partly difficulty of obtaining the elements quite pure, and partly on the incidental to the determinations of the specific heats, and of the lents. But the specific heats of bodies vary with the state of aggre- and also with the limits of the temperature at which they are de- ed. Some, such as potassium, have been determined at tempera- very near their fusing points; others, like platinum, at great dis- from these points. And, doubtless, the principal reason of the ancies is the fact that the determinations have not been made identical physical conditions, and at temperatures equally distant e fusing point.

equivalents of the elements represent the relative weights of equal rs of atoms of these bodies, and the product pc of the specific heat

c into the equivalent p is the *atomic specific heat*, or the quantity of hea necessary to raise the temperature of the same number of atoms by on degree; and Dulong and Petit's law may be thus expressed : *the sam quantity of heat is needed to heat an atom of all simple bodies to the sam extent.*

The atomic heat of a body, when divided by its specific heat, gives th equivalent of a body. Regnault has even proposed to use this relatio as a means of determining the equivalent, and it certainly is of great service in deciding on the equivalent of a body in cases where the chemica relations permit a choice between two or more numbers.

In compound bodies the law also prevails; the product of the specifi heat into the equivalent is an almost constant number, which varies, however, with the different classes of bodies. Thus, for the class of oxides o the general formula RO, it is 11·30; for the sesquioxides R^2O^3, it i 27·15; for the sulphides RS, it is 18·88; and for the carbonates RCO^3, i is 21·54.

The law may be expressed in the following general manner: *Wit compounds of the same formula, and of a similar chemical constitution the product of the atomic weight into the specific heat is a constant quantity.* This includes Dulong and Petit's law as a particular case.

425. **Specific heat of compound bodies.**—In order to deduce th specific heat of the compound from that of its elements, M. Wœstyn ha made the following hypothesis: he assumes that an element, in enterin into combination with others to form a compound body, retains its own specific heat, so that if p, p', p'', ... represent the atomic weights o the elements, and P that of the compound; $c, c' c''$, ... C., the corresponding specific heats, while n, n', n'', ... are the numbers of atom of these simple bodies which make up the molecule of the compound, the relation obtains :

$$PC = npc + n'p'c' + n''p''c'' + \dots .$$

M. Wœstyn has found that the results obtained by calculating, on this hypothesis, the specific heats of the sulphides, iodides, and bromides, agree with experimental results.

426. **Specific heat of gases.**—The specific heat of a gas may be referred either to that of water or to that of air. In the former case, it represents the quantity of heat necessary to raise a given weight of the gas through one degree, as compared with the heat necessary to raise the same weight of water one degree. In the latter case it represents the quantity of heat necessary to raise a given volume of the gas through one degree, compared with the quantity necessary for the same volume of air treated in the same manner.

De la Roche and Berard determined the specific heats of gases in reference to water by causing known volumes of a given gas under constant pressure, and at a given temperature, to pass through a spiral glass tube placed in water. From the increase in temperature of this water, from the other data, the specific heat was determined by a calcul analogous to that given under the method of mixtures. The same p cists also determined the specific heats of different gases relatively to ir, by comparing the quantities of heat which equal volumes of a given and of air at the same pressure and temperature, imparted to equal hts of water. Subsequently to these researches, De la Rive and cet have applied the method of cooling to the same determination; still more recently Regnault has made a series of investigations on alorific capacities of gases and vapours, in which he has adopted, with material improvements, the method of De la Roche and Bernard. has thus obtained the following results for the specific heats of the ous gases and vapours, compared first with an equal weight of water n as unity; secondly, with that of an equal volume of air, referred, as re, to its own weight of water taken as unity.

		Specific heats	
		Equal weights	Equal volumes
	Air	0·2374	0·2374
Simple gases	Oxygen	0·2175	0·2405
	Nitrogen	0·2438	0·2370
	Hydrogen	3·4090	0·2359
	Chlorine	0·1210	0·2962
mpound gases	Binoxide of nitrogen	0·2315	0·2406
	Carbonic oxide	0·2450	0·2370
	Carbonic acid	0·2163	0·3307
	Hydrochloric acid	0·1845	0·2333
	Ammonia	0·5083	0·2966
	Olefiant gas	0·4040	0·4106
apours	Water	0·4805	0·2984
	Ether	0·4810	1·2296
	Alcohol	0·4534	0·7171
	Turpentine	0·5061	2·3776
	Bisulphide of carbon	0·1570	0·4140
	Benzole	0·3754	1·0114

making these determinations the gases were under a constant pres- but variable volume; that is, the gas as it was heated could expand, this is called the *specific heat under constant pressure.* But if the when being heated is kept at a constant volume, its pressure or elastic then necessarily increasing, it has a different capacity for heat; this r is spoken of as the *specific heat under constant volume.* That this r is less than the former is evident from the following considerations: ppose a given quantity of gas to have had its temperature raised $t°$, e the pressure remained constant, this increase of temperature will e been accompanied by a certain increase in volume. Supposing now the gas is so compressed as to restore it to its original volume, the lt of this compression will be to raise its temperature again to a ain extent, say $t'°$. The gas will now be in the same condition as had been heated, and not been allowed to expand. Hence, the same ntity of heat which is required to raise the temperature of a given ht of gas, $t°$, while the pressure remains constant and the volume s, will raise the temperature $t+t'$ degrees if it is kept at a constant volume but variable pressure. The specific heat, therefore, of a gas at constant pressure, c_p is greater than the specific heat under constant volume, c, and they are to each other as $t+t' : t$, that is $\frac{c_1}{c} = \frac{t+t'}{t}$.

It is not possible to determine by direct means the specific heat of gases under constant volume with even an approach to accuracy; and it has always been determined by some indirect method, of which the most accurate is based on the theory of the propagation of sound (217). The latest determination made on this basis gives the number 1·414 for the value of $\frac{c_1}{c}$.

427. **Latent heat of fusion.**—Black was the first to observe that during the passage of a body from the solid to the liquid state, a quantity of heat disappears, so far as thermometric effects are concerned, and which is accordingly said to become latent.

In one experiment he suspended in a room at the temperature 8·5° two thin glass flasks, one containing water at 0°, and the other the same weight of ice at 0°. At the end of half an hour the temperature of the water had risen 4°, that of the ice being unchanged, and it was 10½ hours before the ice had melted and attained the same temperature. Now the temperature of the room remained constant, and it must be concluded that both vessels received the same amount of heat in the same time. Hence 21 times as much heat was required to melt the ice and raise it to 4° as was sufficient to raise the same weight of water through 4°. So that the total quantity of heat imparted to the ice was $21 \times 4 = 84$, and as of this only 4 was used in raising the temperature, the remainder, 80, was used in simply melting the ice.

He also determined this latent heat by immersing 119 parts of ice at 0° in 135 parts of water at 87·7° C. He thus obtained 254 parts of water at 11·6° C. Taking into account the heat received by the vessel in which the liquid was placed, he obtained the number 79·44 as the latent heat of liquidity of ice.

We may thus say:

Water at 0° = ice at 0° + latent heat of liquefaction.

The method which Black adopted is essentially that which is now used for the determination of latent heats of liquids; it consists in placing the substance under examination at a known temperature in the water (or other liquid) of a calorimeter, the temperature of which is sufficient to melt the substance if it is solid, and to solidify it if liquid, and when uniformity of temperature is established in the calorimeter, this temperature is determined. Thus, to take a simple case, suppose it is required to determine the latent heat of liquidity of ice. Let M be a certain weight of ice at zero, and m a weight of water at $t°$ sufficient to melt the ice. The ice is immersed in the water, and as soon as it has melted the final temperature $\theta°$ is noted. The water, in cooling from $t°$ to $\theta°$ has parted with a quantity of heat, $m(t-\theta)$. If x be the latent heat of the ice, it absorbs, in liquefying, a quantity of heat, Mx; but, besides this, the water ich it forms has risen to the temperature θ°, and to do so has required antity of heat, represented by $M\theta$. We thus get the equation

$$Mx + M\theta = m(t-\theta)$$

m which the value of x is deduced.

By this method, and avoiding all sources of error, MM. Desains and De Provostaye found that the latent heat of the liquefaction of ice is 79·25; t is, a pound of ice, in liquefying, absorbs the quantity of heat which ld be necessary to raise 79·25 pounds of water, 1°, or, what is the same ng, one pound of water from zero to 79·25°.

This method is thus essentially that of the method of mixtures; the e apparatus may be used, and the same precautions are required in two cases. In determining the latent heat of liquidity of most solids, different specific heats of the substance in the solid and in the liquid te require to be taken into account. In such a case, let m be the weight the water in the calorimeter (the water equivalents of the calorimeter d thermometer supposed to be included); M the weight of the substance rated on; t the original and θ the final temperature of the calorimeter; the original temperature of the substance; $\mathfrak{T}$ its melting (or freezing) nt; C the specific heat of the substance in the solid state between the nperature and θ; c its specific heat in the liquid state between the nperatures T and $\mathfrak{T}$; and let L be the latent heat sought.

If the experiment be made on a melted substance which gives out heat the calorimeter and is thereby solidified (it is taken for granted that a dy gives out as much heat in solidifying as it absorbs in liquefying), it is in that the quantity of heat absorbed by the calorimeter, $m(\theta-t)$, is de up of three parts: first, the heat lost by the substance in cooling m its original temperature T to the solidifying point $\mathfrak{T}$; secondly, the at given out in solidification, L; and, thirdly, the heat it loses in sinkfrom its solidifying point $\mathfrak{T}$ to the temperature of the water of the orimeter. That is:

$$m(\theta-t) = M\Big[(T-\quad)c + L + (\mathfrak{T}-\theta)C\Big]$$

ence,

$$L = \frac{m(\theta-t)}{M} - (T-\mathfrak{T})c - (\mathfrak{T}-\theta)C.$$

M. Person, who has made several researches on this subject, has tained the following numbers for the latent heats of fusion of several dies:

ater	79·24	Bismuth	12·64
trate of sodium	62·97	Sulphur	9·37
c	28·13	Lead	5·37
ver	21·07	Phosphorus	5·03
	14·25	D'Arcet's alloy	4·50
dmium	13·66	Mercury	2·83

hese numbers represent the number of degrees through which a pound water would be raised by a pound of the body in question in passing n the liquid to the solid state; or, what is the same thing, the number of pounds of water that would be raised 1° C. by one of the b solidifying.

On modern views the heat expended in melting is consumed ir the atoms into new positions; the work, or its equivalent in heat for this, the potential energy they thus acquire, is strictly compa the expenditure of work in the process of raising a weight. When t solidifies, it reproduces the heat which had been expended in lique solid, just as when a stone falls it produces by its impact against th the heat, the equivalent of which in work had been expended in r

428. **Determination of the latent heat of vapours.**—Liqui have seen, in passing into the state of vapour, absorb a very con quantity of heat, which is termed *latent heat of vaporisation.* I mining the heat absorbed in liquids, it is assumed that a va liquefying, gives out as much heat as it had absorbed in becom verted into vapour.

The method employed is essentially the same as that for dete the specific heat of gases. Fig. 322 represents the apparatus M. Despretz. The vapour is produced in a retort, C, where its t ture is indicated by a thermometer. It passes into a worm imm cold water, where it condenses, imparting its latent heat to the cor water in the vessel B. T densed vapour is collecte vessel, A, and its weight re the quantity of vapour wh passed through the worm. T mometers in B give the cl temperature.

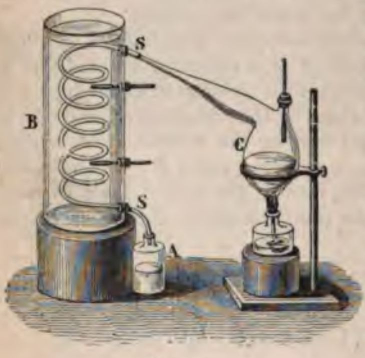


Fig. 322

Let M be the weight of densed vapour, T° its tem on entering the worm, v that of its boiling point, ar latent heat of vaporisation larly, let *m* be the weigh condensing water (compri weight of the vessel B an worm SS *reduced*) in wat be the temperature of the water at the beginning, and θ° its tempe the end of the experiment.

It is to be observed that, at the commencement of the experin condensed vapour passes out at the temperature $t°$, while at the co its temperature is θ°; we may, however, assume that its mean tem during the experiment is $\frac{(t+\theta)}{2}$. The vapour M after condensa therefore parted with a quantity of heat $M\left(T-\frac{t+\theta}{2}\right)c$, while t disengaged in liquefaction is represented by Mx. The quantity absorbed by the cold water, the worm and the vessel is $m(\theta-t)$. Tl

$$Mx+M-\left(-\ \frac{t+\theta}{2}\right)c=m(\theta-t)$$

hich x is obtained. M. Despretz found that the latent heat of s vapour at 100° is 540; that is, a pound of water at 100° absorbs rising as much heat as would raise 540 pounds of water through Regnault found the number 537, and MM. Favre and Silbermann

the case of the latent heat of water we may say,

Steam at 100° = Water at 100° + latent heat of gaseification.

e conversion of a body from the liquid into the gaseous state, as in logous process of fusion, one part of the heat is used in increasing nperature and another in internal work. For vaporisation the portion is consumed in the internal work of overcoming the cal attraction of the particles of liquid, and in removing them to greater distances apart in which they exist in the gaseous state. In n to this there is the external work—namely, that required to overne external pressure, usually that of the atmosphere; and as the e of volume in vaporisation is considerable, this pressure has to be hrough a greater distance. Vaporisation may take place without external work to perform, as when it is effected in vacuo; but r the evaporation is under a high or under a low pressure, on the of a liquid or in the interior, there is always a great consumption in internal work.

Favre and Silbermann's calorimeter.—The apparatus (fig. 323) es a very delicate means of determining the calorific capacity of latent heats of evaporation, and the heat disengaged in chemical

principal part is a spherical iron reservoir, A, full of mercury, of t holds about 50 pounds, and represents, therefore, a volume of more lf a gallon. On the left there are two tubulures, B, in which are wo sheet-iron tubes or *muffles*, projecting into the interior of the Each can be fitted with a glass tube for containing the substance nented upon. In most cases one muffle and one glass tube are ; the two are used when it is desired to compare the quantities of oduced in two different operations. In a third vertical tubulure, C, also a muffle, which can be used for determining calorific capacities gnault's method (410), in which case it is placed beneath the *r* of

tubulure *d* contains a steel piston; a rod, turned by a handle, *m*, hich is provided with a screw thread, transmits a vertical motion to ton; but, by a peculiar mechanism, gives it no rotatory motion. In t tubulure is a glass bulb, *a*, in which is a long capillary glass tube, ided into parts of equal capacity.

ill be seen from this description that the mercury calorimeter is g more than a thermometer with a large bulb and a very capillary it is therefore extremely delicate. It differs, however, from a therter in the fact that the divisions do not indicate the temperature of ercury in the bulb, but the number of thermal units imparted to it substances placed in muffle.

s graduation is effected as follows :- By working the piston the mercury can be made to stop at any point of the tube, *bo*, at which it i desired the graduation should commence. Having then placed in th iron tube a small quantity of mercury, which is not afterwards changed, thin glass tube, *e*, is inserted, which is kept fixed against the buoyancy o the mercury by a small wedge not represented in the figure. The tub being thus adjusted, the point of a bulb tube (see fig. 324) is introduce containing water, which is raised to the boiling point: turning the positio of the pipette, then, as represented on *n′*, a quantity of the liquid flow into the test tube.

The heat which is thus imparted to the mercury makes it expand; th

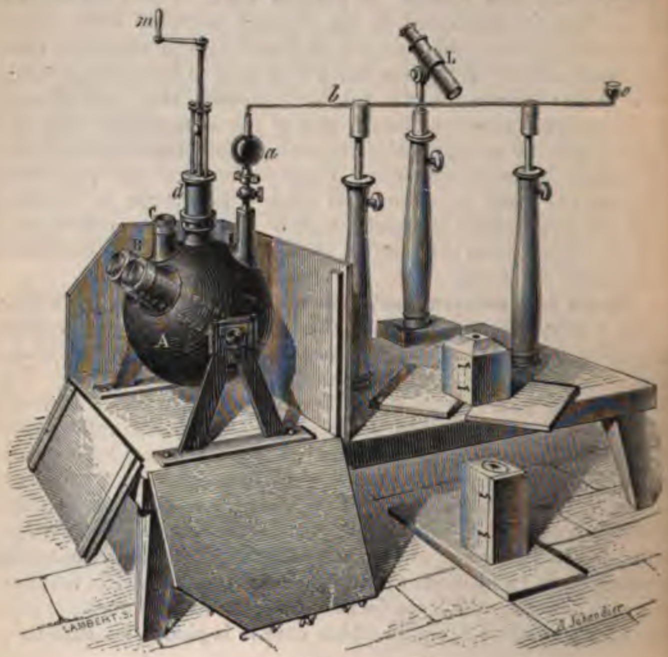


Fig. 323.

column of mercury in *bo* is lengthened by a number of divisions, which we shall call *n*. If the water poured into the test glass be weighed, and if its temperature be taken when the column *bo* is stationary, the product of the weight of the water into the number of degrees through which it has fallen indicates the number of thermal units which the water gives up t the entire apparatus (415). Dividing by *n* this number of thermal units the quotient gives the number *a* of thermal units corresponding to single division of the tube *bo*.

In determining the specific heat of liquids, a given weight, M, of th liquid in question is raised to the temperature T, and is poured in th le C. Calling the specific heat of the liquid C, its final temperature θ, d n the number of divisions by which the mercurial column bo has vanced, we have

$$Mc(T-\theta)=na, \text{ from which } c=\frac{na}{M(T-\theta)}.$$

The boards represented round the apparatus are hinged so as to form a x, which is lined with eider down or wadding to prevent any loss of

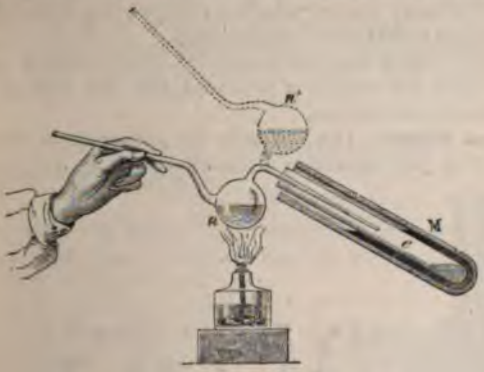


Fig. 324.

eat. It is closed at the top by a board, which is provided with a suitable se, also lined, which fits over the tubulures d' and a. A small magnifying lass which slides along the latter enables the divisions on scale to be ead off.

430. **Examples.**—I. What weight of ice at zero must be mixed with 9 ounds of water at 20° in order to cool it to 5°?

Let M be the weight of ice necessary; in passing from the state of ice o that of water at zero, it will absorb 80M thermal units; and in order to aise it from zero to 5°, 5M thermal units will be needed. Hence the total heat which it absorbs is $80M+5M=85M$. On the other hand, the heat given up by the water in cooling from 20° to 5° is $9\times(20-5)=135$. Consequently,

$$85M=135; \text{ from which } M=1{\cdot}588 \text{ pounds.}$$

II. What weight of steam at 100° is necessary to raise the temperature of 208 pounds of water from 14° to 32°?

Let p be the weight of the steam. The latent heat of steam is 540°, and consequently p pounds of steam in condensing into water give up a quantity of heat, $540p$, and form p pounds of water at 100°. But the temperature of the mixture is 32°, and therefore p gives up a further quantity of heat $p(100-32)=68p$, for in this case c is unity. The 208 pounds of water in being heated from 14° to 32° absorb $208(32-14)=3744$ units. Therefore,

$$540p+68p=3744; \text{ from which } p=6{\cdot}158 \text{ pounds.}$$

CHAPTER X.

STEAM ENGINES.

431. **Steam engines.**—*Steam engines* are machines in which the ela force of aqueous vapour is used as motive force. In the ordinary engi the alternate expansion and condensation of steam imparts to a piston alternating rectilinear motion, which is changed into a circular motion means of various mechanical arrangements.

Every steam engine consists essentially of two distinct parts : the a paratus in which the vapour is produced, and the engine proper. W shall first describe the former.

432. **Steam boiler.**—The boiler is the apparatus in which steam generated. Fig. 325 represents a side view, and fig. 326 a cross sect

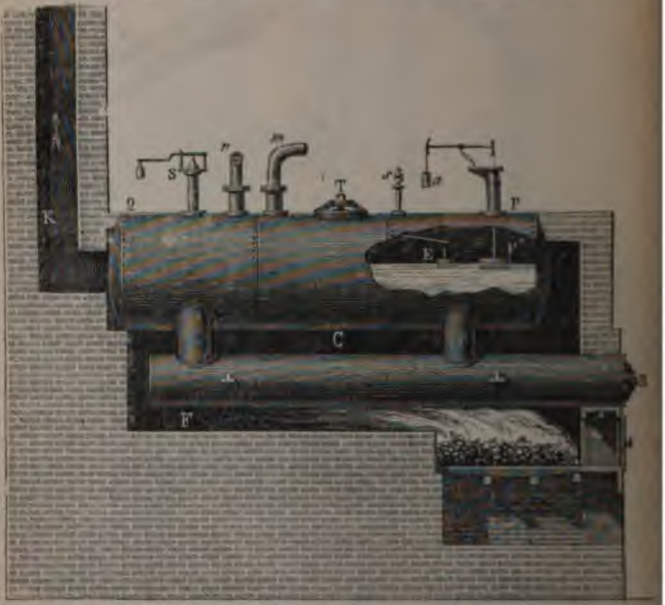


Fig. 325

of a cylindrical boiler, such as are used for fixed engines ; those of lo motives and of steam vessels are very different.

It is a long wrought-iron cylinder, PQ, with curved ends, bene which there are two smaller cylinders, BB, of the same material, communicating with the boiler by two tubes. Only one of these cylind is represented in the figure. They are called *heaters*, and are quite of water, while the boiler is only about half full.

In order to multiply the heating surface, and utilise all the heat carried off by the products of combustion, the latter are made to circulate through brick conduits which surround the sides of the heaters and of the boiler. These conduits, which are called *flues*, divide the furnace into two horizontal compartments, FF and DCD (fig. 326). The upper compartment is moreover divided into three distinct flues, D, C, D, by two vertical divisions, which are not represented in the drawing, and which correspond to the two sides of the boiler. The flame and the products of combustion, which first sweep below the heaters from back to front, return in the opposite direction by the central flues C; then, dividing, they pass by the lateral flues into the chimney K, where they are lost in the atmosphere.

Explanation of Figures 325 *and* 326.

E. Float of the safety whistle, *s*.

FF. Furnace.

F. *Float*, to show the level of the water in the boiler. It consists of a rectangular piece of stone partially immersed in water, as seen through the space which is represented as left open. The stone, which is suspended at one end of a lever, is kept poised by the loss of weight which it sustains by immersion in the water, and by a weight, *a*, at the other end of the lever. As long as the water is at the desired height, the lever which sustains the float remains horizontal; but it sinks when there is too little water, and rises in the contrary direction when there is too much. Guided by these indications, the stoker can regulate the supply of water.

K. Chimney, which has usually a great height so as to increase the draught.

S. *Safety valve*, described under Papin's digester (343).

T. *Man-hole*, an aperture by which the boiler can be repaired and cleansed. This is self-closing, and consists of a cover fitting against the inside edges. It is kept in position by a screw, which also presses it strongly against the sides. Thus the greater the internal pressure, the more firmly is the cover pressed against the sides, and the more completely does it close.

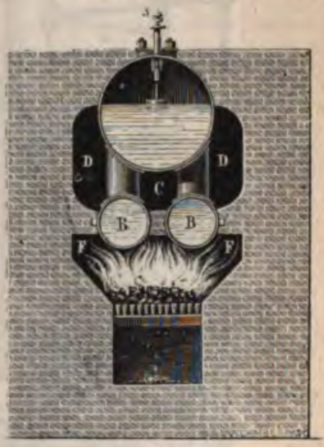


Fig. 326.

a. Counterpoise of the float.

m. Tube which leads the steam to the tube *c* of the *valve chest*.

n. Tube for the admission of feed water for the boiler.

t. *Safety whistle*—so called because it gives a whistle when there is t enough water in the boiler; a circumstance which might produce an cident. As long as the level of the water is not too low in the boiler, the steam does not pass into the whistle ; but if the level sinks belo certain point, a small float, E, which closes the bottom of the whis sinks, and the steam escapes ; in so doing it grazes against the edge o thin metal plate, which it sets in vibration, and produces a sharp a loud sound. This steam whistle is the sound frequently heard up railways ; it is used as a signal in locomotives.

433. **Double action, or Watt's engine.**—In the *double acting ste engine*, the steam acts alternately above and below the piston. It is a known as *Watt's engine*, from its illustrious inventor.

We shall first give a general idea of this engine, and shall then descr each part separately. On the left of the fig. 327 is the *cylinder* wh

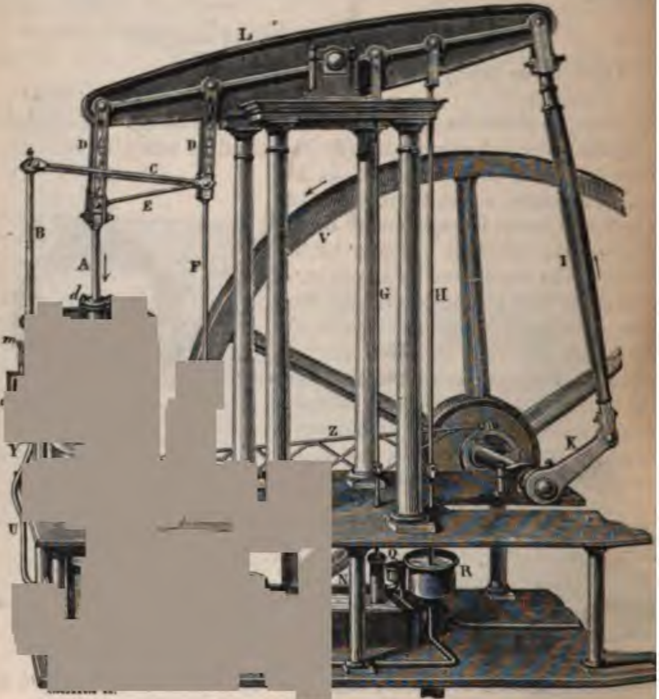


Fig. 327.

receives the steam from the boiler. A part of its side is rep as being left open, and a piston, P, can be seen which is move nately up and down by the pressure of the steam above or b piston. By the piston rod A this motion is transmitted to a h lever, L, called the *beam*, which is supported by four iron colum beam transmits its motion to a *connecting rod*, I, working on K, to which it imparts a continuous rotatory motion. The cran to a horizontal *shaft*, which turns with it, and, by means of wheels or endless bands, this shaft sets in motion various machines, such as spinning frames, saw mills, lathes, etc.

On the left of the cylinder is a valve chest, where, by a mechanism, which will presently be described, the steam passes alternately above and below the piston. Now, after its action on either face of the piston, it must disappear, for otherwise a pressure would be exerted in two opposite directions, and the piston would remain at rest. To effect this, the steam, after it has acted on one side of the piston, passes into a vessel, O, called the *condenser*, into which cold water is injected. It is almost ompletely condensed there, and consequently the pressure ceases in hat part of the cylinder which is in communication with the condenser, nd as there is now pressure on only one face of the piston, it either rises r sinks.

The use of the condenser depends upon Watt's law of vapours (334), hat when two vessels communicating with each other, and containing aturated vapour, are at different temperatures, the tension is the same n both vessels, and is that corresponding to the temperature of the colder essel.

The injected water is rapidly heated by the condensation of the steam, and must be constantly renewed. This is effected by means of two pumps; one, M, is called the *air pump*, and pumps, from the condenser, the heated water which it contains, and also the air which was dissolved in the water of the boiler, and which passes with the steam into the cylinder and condenser; the other, R, is called the *cold water pump*, and forces cold water from a well, or from a river, into the condenser.

A third pump, Q, which is called the *feed pump*, utilises the heated water by forcing it from the condenser into the boiler.

Double acting steam engine.

A. *Piston rod* connected with a parallel motion, and serving to transmit to the beam the upward and downward motion of the piston.

B. Rod fixed to the cylinder, or elsewhere, and supporting the guiding arm or radius rod, C.

C. Double guiding arm directing the parallel motion.

DDDE. Rods forming at the end of the beam a *parallel motion*, to which is fixed the piston rod, and the object of which is to guide the motion of this rod in a straight line.

F. Rod of the *air pump*, which removes from the condenser the air and heated water which it contains.

G. Rod of the *feed pump*, which forces into the boiler through the tube S the heated water pumped from the condenser.

H. Rod of the *cold water pump*, which supplies the cold water necessary for condensation.

I. *Connecting rod*, which transmits the motion of the beam to the rank.

K. *Crank*, which imparts the motion of the rod to the horizontal shaft.

L. *Beam*, which moves on an axle in its middle, and transmits the motion of the piston to the connecting rod I.

M. Cylinder of the air pump, in connection with the condenser O.

N. Reservoir for the heated water pumped by the air pump from the condenser.

O. Condenser into which cold water is injected, to condense the steam after it has acted on the piston.

P. *Metallic piston*, moving in a cast-iron cylinder; this piston receives the direct pressure of the steam, and transmits the motion to all parts of the machine.

Q. Feeding force pump, which sends the water into the boiler.

R. Cold water pump.

S. Pipe by which the hot water from the feed-pump passes into the boiler.

T. Pipe by which cold water from the reservoir of the pump, R, passes into the condenser.

U. Pipe by which the steam from the cylinder passes into the condenser after acting on the piston.

V. Large iron wheel, called the *fly wheel*, which, by its inertia, serves to regulate the motion, especially when the piston is at the top or bottom of its course, and the crank K at its *dead points*.

Y. Bent lever which imparts the motion of the eccentric *e* to the slide valve *b*.

Z. Eccentric rod.

a. Aperture which communicates both with the upper and lower part of the cylinder, according to the position of the slide valve, and by which steam passes into the condenser through the tube U.

b. Rod transmitting motion to the *slide valve*, by which steam is alternately admitted above and below the piston. This will be described in greater detail in the next article.

c. Aperture by which steam reaches the valve chest.

d. *Stuffing box*, in which the piston rod works without giving exit to the steam.

e. *Eccentric*, fixed to the horizontal shaft, and rotating in a collar, to which the rod Z is attached.

m. Rod which connects the rod of the slide valve *b* to the bent lever Y, and to the eccentric.

The lower part of the figure does not exactly represent the usual arrangement of the pumps. The drawing has been modified in order more clearly to show how these parts work, and their connection with each other.

434. **Distribution of the steam. Eccentric.**—Fig. 328 represents the details of the *valve chest* or arrangement for the *distribution of steam*. The steam from the boiler passes by a pipe, *c*, into a cast-iron box on the side of the cylinder. In the sides of the cylinder there are three openings or *ports*, *u*, *n*, and *a*, of which *u* communicates by an

nal conduit with the upper part of the cylinder, and *n* with the r part. A slide, *t*, works over these three orifices. It is fixed to a cal rod, *b*, which is jointed at *m* to a larger rod, *d*, and receives an ard and downward motion from the bent lever *yo*S, attached to the ntric rod. When the slide is at the top of its course, as shown in igure, the steam passes through *n* into the lower part of the cylinder, e the steam cannot pass through the orifice *u*, for it is covered by the

ut the vapour which is above the piston passes through *u* and through o the hole *r*, from which it enters the condenser. The piston is then pressed upwards, and therefore ascends.

hen the slide is at the bottom of its course, the steam enters the nder by the aperture *u*, and passes from the lower part of the cylinder

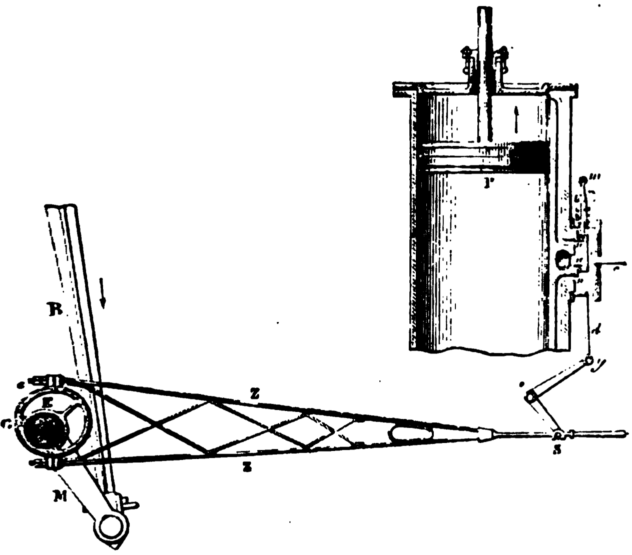


Fig. 328.

the condenser by *n* and *a*. The piston consequently descends, and motion goes on for each displacement of the slide.

he upward and downward motion of the slide is effected by means of *eccentric*. This is a circular piece, E, fixed to the horizontal shaft, but in such a manner that its centre does not coincide with the axis this shaft. The eccentric works with gentle friction in a collar, C, to ich the rod ZZ is fixed. The collar, without rotating, follows the tion of the eccentric, and receives an alternating motion in a horizontal ection, which it communicates to the lever S*oy*, and from thence to the de.

435. **Single acting engine.**—In a *single acting engine* the steam on y ts on the upper face of the piston ; a counterpoise fixed to the other

end of the beam makes the piston rise. These engines were first c structed by Watt for pumping water from mines, and are still used this purpose in Cornwall, and also for the supply of water to tow They are preferred for these purposes from their simplicity, but for ot ses they have been superseded by the double action engine.

Fig. 329 represents a section. The beam BB is of wood, with wooc

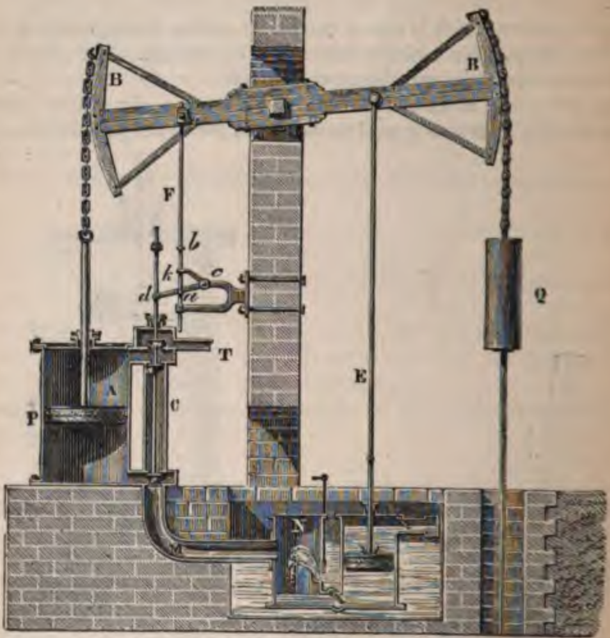


Fig. 329.

segments at each end, to which chains are attached. One of th chains is connected with the piston, and the other with the pun On the right of the cylinder A is a valve chest, C, into which ste passes from the boiler by the tube T. There are three valves, *m*, *n*, a *o*, on a vertical rod. The valves *m* and *o* open upwards, the valve downwards.

When *m* and *o* are open, as shown in the drawing, the steam pass through the tube T, over the piston, while the steam, which is below, forced into the condenser through the tube M. The piston therefo descends. The rod, on which are the valves *m*, *n*, and *o*, is connecte with a bent lever, *dck*, moving on a joint *c*. This bent lever closes ar opens the valves. For this purpose there are two catches, *b* and *a*, on rod, F, connected with the beam, by means of which the rod work against the end of the bent lever. From the arrangement of the valves, as represented in the drawing, the piston sinks and carries with it the rod F, and, consequently, the catch strikes against the lever, and makes it sink at the same time as the rod *dmo*; the valves *m* and *o* then close, while *n* opens.

The communication with the boiler as well as with the condenser is now cut off, and the steam which has made the piston sink passes below by the pipe C. As it presses equally on both faces, the piston would remain at rest, but it rises in consequence of the traction of the weight Q. Very little force is necessary for this; for the pump, the rod of which is fixed to the weight Q, only requires power when its piston rises. When the piston P is at the top of its course, the catch *a* strikes in turn against the lever *k*, raises the rod *dmo*, the steam again passes to the top of the piston, which again descends, and so on.

436. **Locomotives.**—*Locomotive engines*, or simply *locomotives*, are steam engines which, mounted on a carriage, propel themselves by transmitting their motion to wheels.

The parallel motion, the beam, and the fly wheel form no part of a locomotive. The principal parts are the *framework*, the *fire box*, the *casing* of the boiler, the *smoke box*, the *steam cylinders* with their valves, the *driving wheels*, and the *feed pump*.

The framework is of oak, and rests on the axles of the wheels. Fig. 330 represents the driver of the locomotive in the act of opening the regulator valve I, placed in the upper part of the *steam dome*. In the lower part of this is the fire box, from whence the flame and the products of combustion pass into the smoke box Y, and then into the chimney Q, after having previously traversed 125 brass *fire tubes* which pass through the boiler. The boiler, which connects the fire box with the smoke box, is made of iron, and is cylindrical. It is cased with staves of mahogany, which, being a bad conductor, prevents its cooling too rapidly. The steam passes from the boiler into two cylinders placed on either side of the smoke box. There, by means of a steam chest similar to that already described, it acts alternately on the two faces of the piston, the motion of which is transmitted to the axle of the large driving wheels. This arrangement of the slide valve is not seen in the drawing, because it is placed under the frame between the two cylinders. After having acted on the pistons, the steam is forced through the blast pipe E into the chimney, thus increasing the draught.

The motion of the pistons is transmitted to the two large driving wheels by two connecting rods, which, by means of cranks, connect the piston rods with the axles of the wheels. The alternating motion of the slide valve is effected by means of eccentrics placed on the axles of the large wheels.

The feeding or supply of water to the boiler is obtained by means wo pumps placed under the frame, and moved by eccentrics. These ops suck the water from a reservoir placed on the *tender*, which is arriage attached to the locomotive for carrying the necessary water d coal.

Explanation of Figure 330.

A. Copper tube, into which steam passes by the extremity I, a which, dividing at the other end into two branches, conveys the stea the two cylinders which contain the pistons.

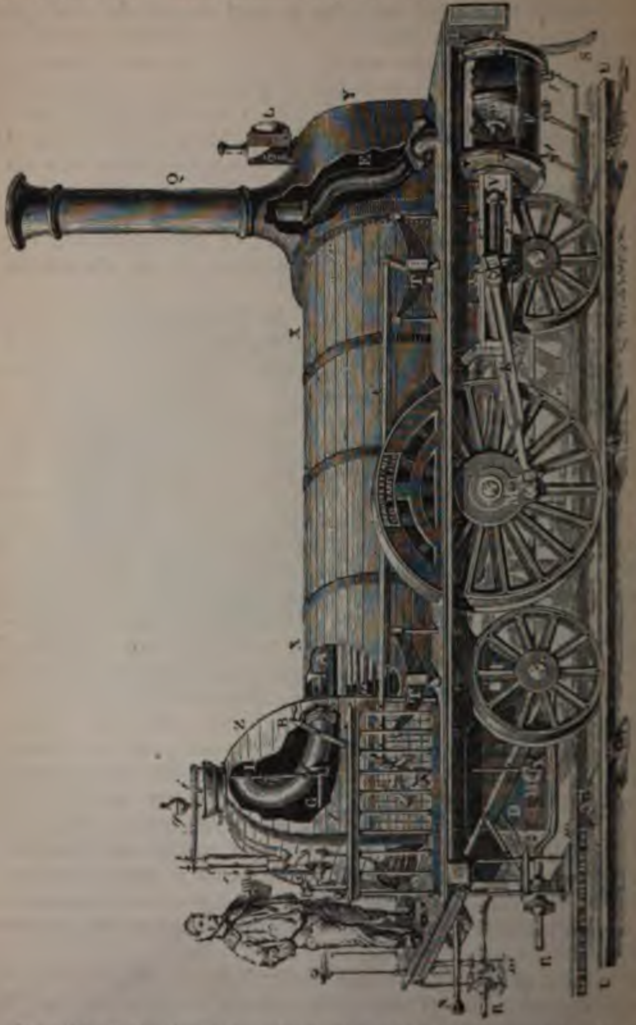


Fig. 330.

B. Handle of the lever, by which the motion is reversed. It impa motion to a rod, C, which communicates with the steam chest.

C. Rod by which the motion is reversed.

D. Lower part of the fire box and ash pan.

E. Escape pipe for the steam after acting on the pistons.

F. Iron cylinder containing a piston, P. There is one of these on each e of the engine, and the one in front is represented as being left open order that the piston may be seen.

G. Rod which opens the regulator valve I, in order to allow the steam pass into the tube A. In the drawing the driver holds in his hand the er which moves this rod.

H. Cock for blowing off water from the boiler.

I. Regulator valve, which is opened and closed by hand, so as to regu-e the quantity of steam passing into the cylinders.

K. Large rod connecting the head of the piston rod with the crank M the driving wheel.

L. Lamp for use by night.

M. Crank, which transmits the motion of the piston to the axle of the rge wheel.

N. Coupling iron, by which the tender is attached.

O. Fire door, by which coke is introduced.

P. Metallic piston, the rod of which is connected with the rod K.

Q. Chimney, by which both steam and smoke escape.

R, R. Feed pipes, through which the water in the tender passes to two rce pumps, which are not shown in the drawing.

S. Guard for removing obstructions on the rails.

T, T. Springs on which the engine rests.

U, U. Iron rails fixed in chairs on wooden sleepers.

V. Frame of the stuffing box of the cylinder.

X, X. Cylindrical boiler, covered with mahogany staves, which, from their bad conductivity, hinder the loss of heat. The level of the water is just below the tube A. In the water are the tubes *aa*, through which the smoke and flames pass into the smoke box.

Y. Smoke box, in which the fire tubes *a* terminate.

Z, Z. Fire box, covered by a dome, into which the steam passes.

a. Brass tubes, of which there are 125, open at both ends, and terminating at one end in the fire box, and at the other in the smoke box. These tubes transmit to the water the heat of the fire.

bb. Toothed segment, placed on the side of the fire box, and in which e arm of the lever B works. When the handle is pushed forward or lled back as far as it can go, the engine is in full forward or backward ar respectively; the intermediate teeth give various rates of expansion backward and forward motion, the middle tooth being a dead point.

. Cases containing springs by which the safety valves *i* are regulated.

. Signal whistle.

Safety valves.

, *m*. Steps.

. Glass tube, showing the height of water in the boiler.

, *r*. Guiding rods, for keeping the motion of the pistons in a straight

.

t. Blowing-off taps, for use when the pistons are in motion.

. Rod by which motion is transmitted to these taps.

437. **Reaction machines. Eolipyle.**—In *reaction machines* acts by a reactive force like water in a hydraulic tourniquet (204). idea of these machines is by no means new; Hero of Alexandria, invented the fountain which bears his name, described the follo apparatus, which is known as the reaction machine.

It consists of a hollow metallic sphere which rotates on two p (fig. 331). At the ends of a diameter are two tubulures, pierced lat

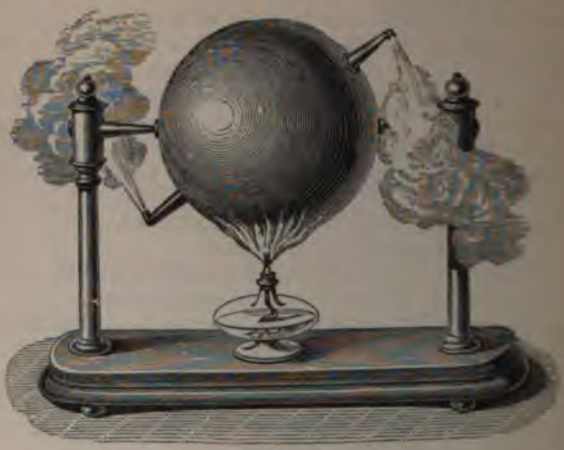


Fig. 331.

in opposite directions by orifices through which vapour escapes. is introduced into this apparatus by heating it, and then allowing cool in cold water. If the apparatus be then heated to boiling, the v disengaged imparts to it a rotatory motion, which is due to the pre of the vapour on the side opposite to that from which it escapes.

Numerous attempts have been made to use this reactive force o vapour on a large scale as a motive force, and endeavours have also made to cause steam to act by impulse by directing a jet of steam o float board of a paddle wheel; but in both cases the steam exerts b means so great an effect as is obtained when it acts by expansion piston.

438. **Various kinds of steam engines.**—A *low pressure engine* i in which the tension of the vapour does not much exceed an atmosp and a *high pressure engine* is one in which the pressure of the s usually exceeds this amount considerably. Low pressure engine mostly *condensing engines*; in other words, they generally have a denser where the steam becomes condensed after having acted o piston: on the other hand, *high pressure engines* are frequently with condenser; the locomotive is an example.

If the communication between the cylinder and boiler remains during the whole motion of the piston, the steam retains essentiall same elastic force, and is said to act *without expansion*; but if, by a suitable arrangement of the slide valve, the steam ceases to pass into the cylinder when the piston is at $\frac{2}{3}$ or $\frac{3}{4}$ of its course, then the vapour *expands*; that is to say, in virtue of its elastic force, which is due to the high temperature, it still acts on the piston and causes it to finish its course. Hence a distinction is made between *expanding* and *non-expanding* engines.

439. **Work of an engine. Horse-power.**—The work of an engine is measured by the

Mean pressure on piston × area of piston × length of stroke.

In England the unit of work is the *foot-pound*; that is, the work performed in raising a weight of one pound through a height of a foot. Thus, to raise a weight of 14 pounds through a height of 20 feet would require 280 foot-pounds. In France the *kilogrammeter* is used; that is, the work performed in raising a kilogramme through a metre. This unit corresponds to 7·233 foot-pounds.

The *rate of work* in machines is the amount of work performed in a given time; a second or an hour, for example. In England the rates of work are compared by means of *horse-power*, which is a conventional unit, and represents 550 foot-pounds in a second. In France a similar unit is used, called the *cheval vapeur*, which represents the work performed in raising 75 kilogrammes through one metre in a second. It is equal to about 542 foot-pounds per second.

The useful effect of an engine is only about 0·5 to 0·7 of the calculated theoretical effect; the unavoidable resistance and the motion of the various parts of the machine consume a portion. If the work be calculated from the heat known to be produced from a given weight of combustible, the discrepancy is far greater. The best Cornish engines do not give more than 14 per cent. of the theoretical yield of the combustible.

440. **Hirn's experiments.**—Hirn made an important series of experiments in order to determine by means of the steam engine the mechanical equivalent of heat. On the one hand, steam of known temperature and pressure was allowed to act upon the steam engine, which was one of 100 horse-power. The amount of heat contained in it could be readily calculated. The amount of work which the engine performed was also determined by means of a dynamometer. The steam was ultimately condensed in the condenser, and the amount of heat could readily be measured by known calorimetrical methods. It was found in all cases less than that which originally passed into the engine, and the difference represented the amount of heat which had been converted into work in the engine; in Hirn's experiments, for every unit of heat which had disappeared, 1354 units of work had been performed; a result, considering the difficulty of the experiments, closely agreeing with the best determinations (461).

CHAPTER XI.

SOURCES OF HEAT AND COLD.

441. **Different sources of heat.**—The following different sources heat may be distinguished: i. the *mechanical sources*, comprising frictio percussion, and pressure ; ii. the *physical sources*—that is, solar radiatio terrestrial heat, the molecular actions, the changes of condition, and ele tricity ; iii. the *chemical sources*, or molecular combinations, and mo especially combustion.

In what follows it will be seen that heat may be produced by reversi its effects ; as, for instance, when a liquid is solidified or a gas compress (443); though it does not necessarily follow that the reversal of its effec in all cases causes heat to be produced—instead of it, an equivalent some other form of energy may be generated.

In like manner heat may be caused to disappear, or cold be produce when a change such as heat can produce is brought about by other mean as when a liquid is vaporised or a solid liquefied by solution ; thou here also the disappearance of heat is not always a necessary consequen of the production by other means of changes such as might be effected heat.

MECHANICAL SOURCES.

442. **Heat due to friction.**—The friction of two bodies, one against t other, produces heat, which is greater the greater the pressure and t more rapid the motion. For example, the axles of carriage wheels, their friction against the boxes, often become so strongly heated as take fire. By rubbing together two pieces of ice in a vacuum below zer Sir H. Davy partially melted them. In boring a brass cannon Rumf found that the heat developed in the course of 2½ hours was sufficient raise 26½ pounds of water from zero to 100°, which represents 26 thermal units (413). At the Paris Exhibition, in 1855, MM. Beaumo and Mayer exhibited an apparatus, which consisted of a wooden co covered with hemp, and moving with a velocity of 400 revolutions i minute, in a hollow copper cone, which was fixed and immersed in t water of an hermetically-closed boiler. The surfaces were kept cover with oil. By means of this apparatus 88 gallons of water were rais from 10 to 130 degrees in the course of a few hours.

In the case of flint and steel, the friction of the flint against the ste raises the temperature of the metallic particles, which fly off heated such an extent that they take fire in the air.

Dr. Tyndall has devised an experiment by which the great heat d veloped by friction is illustrated in a striking manner. A brass tu (fig. 332), about 4 inches in length and ¾ of an inch in diameter, is fixe on a small wheel. By means of a cord passing round a much larger on this tube can be rotated with any desired velocity. The tube is thr parts full of water, and is closed by a cork. In making the experimen the tube is pressed between a wooden clamp, while the wheel is rotate th some rapidity. The water rapidly becomes heated by the friction, d its temperature soon exceeding the boiling point, the cork is pro- ed to a height of several yards by the elastic force of the steam.

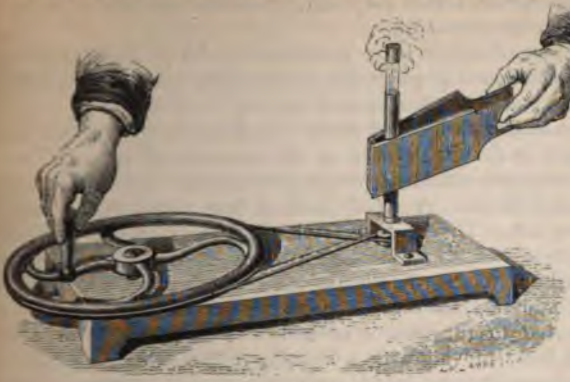


Fig. 332.

443. **Heat due to pressure and percussion.**—If a body be so com- ressed that its density is increased, its temperature rises according as he volume diminishes. Joule has verified this in the case of water and f oil, which were exposed to pressures of 15 to 25 atmospheres. In the se of water at 1·2° C., increase of pressure caused lowering of tempera- re, a result which agrees with the fact that water contracts by heat at is temperature. Similarly, when weights are laid on metallic pillars, at is evolved, and absorbed when they are removed. So in like manner e stretching of a metallic wire is attended with a diminution of tem- erature.

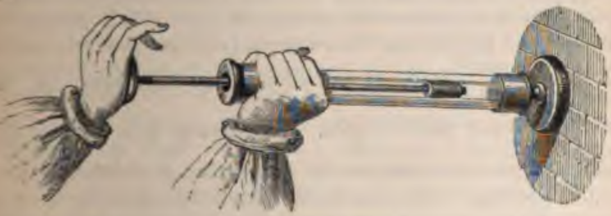


Fig. 333.

The production of heat by the compression of gases is easily shown means of the *pneumatic syringe* (fig. 333). This consists of a glass be with thick sides, closed hermetically by a leather piston. At the ttom of this there is a cavity in which a small piece of tinder is placed. he tube being full of air, the piston is suddenly plunged downwards; e air thus compressed disengages so much heat as to ignite the tinder, hich is seen to burn when the piston is rapidly withdrawn. The in- mmation of the tinder in this experiment indicates a temperature of a least 300°. At the moment of compression a bright flash is observed, which was originally attributed to the high temperature of the air; but it is simply due to the combustion of the oil which greases the piston. Instead of the tinder, cotton very slightly moistened with ether or bisul-phide of carbon may be used.

The elevation of temperature produced by the pressure in the above experiment is sufficient to effect the combination, and therefore the deto-nation, of a mixture of hydrogen and oxygen.

Percussion is also a source of heat. In firing shot at an iron target, a sheet of flame is frequently seen at the moment of impact; and Mr. Whitworth has used iron shells which are exploded by the concussion on striking an iron target. A small piece of iron hammered on the anvil becomes very hot. The heat is not simply due to an approximation of the molecules—that is, to an increase in density—but arises from a vibra-tory motion imparted to them; for lead, which does not increase in density by percussion, nevertheless becomes heated.

The heat due to the impact of bodies is not difficult to calculate. Whenever a body moving with a velocity v is suddenly arrested in its motion, by whatever cause, its *vis viva* is converted into heat. This holds equally whatever be the cause to which the motion is due; whether it be that acquired by a stone falling from a height; by a bullet fired from a gun, or the rotation of a copper disc by means of turning table. The *vis viva* of any moving body is expressed by $\frac{mv^2}{2}$; or in foot-pounds by $\frac{wv^2}{2g}$, where w is the weight in pounds, v the velo-city in feet per second, and g is about 32; and if the whole of this be converted into heat, its equivalent in thermal units will be $\frac{wv^2}{2g \times 1390}$. Suppose, for instance, a lead ball weighing a pound be fired from a gun, and strike against a target, what amount of heat will it produce? W may assume that its velocity will be about 1,600 per second; then its v *viva* will be $\frac{1 \times 1600^2}{2 \times 32} = 40{,}000$ foot-pounds, the equivalent of which in heat is $\frac{40{,}000}{1390} = 28{\cdot}7$ thermal units. If we assume that the heat is equally distributed between the ball and the target, then the share of the former will be 14·3 thermal units; and if, for simplicity's sake, we assume that its temperature is originally zero, then, taking its specific heat at 0·0314, w shall have

$$1 \times 0{\cdot}0314 \times t = 14{\cdot}3 \text{ or } t = 457°.$$

which is a temperature considerably above that of the melting point lead (312).

By similar methods Mayer has calculated that if the motion of th earth were suddenly arrested the temperature produced would be sufficien to melt and even volatilise it; while, if it fell into the sun, as much he would be produced as results from the combustion of 5,000 spheres carbon the size of our globe.

PHYSICAL SOURCES.

444. **Solar radiation.**—The most intense of all sources of heat is the n. The cause of its heat is unknown ; some have considered it to be an nited mass experiencing immense eruptions, while others have regarded as composed of layers acting chemically on each other like the couples f a voltaic battery, and giving rise to electrical currents, which produce ght and solar heat. On both hypotheses the incandescence of the sun uld have a limit.

Different attempts have been made to determine the quantity of heat nually emitted by the sun. M. Pouillet, by means of an apparatus hich he calls a *pyrheliometer*, has calculated that if the total quantity f heat which the earth receives from the sun in the course of a year were mployed to melt ice, it would be capable of melting a layer of ice all ound the earth of 35 yards in thickness. But from the surface which e earth exposes to the solar radiation, and from the distance which parates the earth from the sun, the quantity of heat which the earth ceives can only be $\frac{1}{2,381,000,000}$ of the heat emitted by the sun.

Faraday has calculated that the average amount of heat radiated in a y on each acre of ground in the latitude of London is equal to that hich would be produced by the combustion of sixty sacks of coal.

Various hypotheses have been propounded to account for the inariability in the amount of heat emitted by the sun. The most probable pposition is that originally put forth by Mayer, but which has been eveloped by Waterston and Sir W. Thomson, according to which the heat hich the sun loses by radiation is replaced by the fall of *meteoric stones* or *rolites* against its surface. These are what we know as shooting stars, hich often appear in the heavens with great brilliancy, especially on the th August and 15th November. These fall against the sun with a elocity far transcending anything met with on the surface of our globe, nd by their impact develop an amount of heat which more than comensates what the sun loses by radiation. It has been calculated that an mount falling into the sun every year which would not increase its ickness by more than 21 yards would be sufficient for this purpose.

Tait

445. **Terrestrial heat.**—Our globe possesses a heat peculiar to it, hich is called the *terrestrial heat*. The variations of temperature which ccur at the surface gradually penetrate to a certain depth, at which their fluence becomes too slight to be sensible. It is hence concluded that e solar heat does not penetrate below a certain internal layer, which is lled the *layer of constant temperature* : its depth below the earth's ternal surface varies, of course, in different parts of the globe ; at Paris is about 30 yards, and the temperature is constant at 11·8° C.

Below the layer of constant temperature, the temperature is observed increase, on the average, 1° C. for every 90 feet. This increase has en verified in mines and artesian wells. According to this, at a depth 3,000 yards, the temperature of a corresponding layer would be 100°, d at a depth of 20 to 30 miles there would be a temperature sufficient

to melt all substances which exist on the surface. Hot sprin
volcanoes confirm the existence of this central heat.

Various hypotheses have been proposed to account for the exist
this central heat. That most usually admitted by physicists is
earth was originally in a liquid state in consequence of the high te
ture, and that by radiation the surface has gradually solidified, s
form a solid crust. The thickness of this crust is not believed to
than 40 to 50 miles, and the interior is probably still in a liqui
The cooling must be very slow, in consequence of the imperfect
tivity of the crust. For the same reason the central heat does not
to raise the temperature of the surface more than $\frac{1}{36}$ of a degree.

446. **Heat produced by absorption and imbibition.**—Molecu
nomena, such as imbibition, absorption, capillary actions, are
accompanied by disengagement of heat. Pouillet found that whe
liquid is poured on a finely-divided solid, an increase of tempe
produced which varies with the nature of the substances. Wi
ganic substances, such as metals, the oxides, the earths, the incre
of a degree; but with organic substances, such as sponge, flour,
roots, dried membranes, the increase varies from 1 to 10 degrees.

The absorption of gases by solid bodies presents the same phen
Döbereiner found that when platinum, in the fine state of division
as platinum black, is placed in ox
absorbs many hundred times its volu
that the gas is then in such a state of
and the temperature so high, as to g
to intense combustions. Spongy p
produces the same effect. A jet of h
directed on it takes fire.

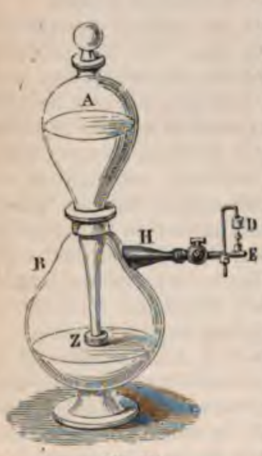


Fig. 334.

The apparatus known as *Döb*
Lamp depends on this property of
divided platinum. It consists of tw
vessels (fig. 334). The first, A, fits
lower vessels by means of a tubulur
closes it hermetically. At the extr
the tubulure there is a mass of
immersed in dilute sulphuric acid.
chemical action of the zinc on the dil
hydrogen gas is generated, which, fin
issue, forces the liquid out of the v
into the vessel A, so that the zinc i
contact with the liquid. The stoppe
upper vessel is raised to give exit to the air in proportion as th
rises. On a copper tube, H, fixed in the side of the vessel B, th
small cone, E, perforated by an orifice; above this there is some
platinum in the capsule D.

As soon now as the cock, which closes the tube H, is ope
hydrogen escapes, and coming in contact with the spongy plat
ignited.

M. Favre has found that when a gas is absorbed by charcoal the amount of heat produced by the absorption of a given weight of sulphurous acid, or of protoxide of nitrogen, greatly exceeds that which is disengaged in the liquefaction of the same weight of gas; for carbonic acid, the heat produced by absorption, exceeds even the heat which would be disengaged by the solidification of the gas. The heat produced by the absorption of these gases cannot, therefore, be explained by assuming that the gas is liquefied, or even solidified in the pores of the charcoal. It is probable that it is due to that produced by the liquefaction of the gas, and to the heat due to the imbibition of the liquid so produced in the charcoal.

The heat produced by the changes of condition has been already treated of in the articles *solidification* and *liquefaction*; the heat produced by electrical action will be discussed under the head of *Electricity*.

CHEMICAL SOURCES.

447. **Chemical combinations. Combustion.**—Chemical combination are usually accompanied by a certain elevation of temperature. When these combinations take place slowly, as when iron oxidises in the air, the heat produced is imperceptible; but if they take place rapidly, the disengagement of heat is very intense. The same quantity of heat is produced in both cases, but when evolved slowly it is dissipated as fast as formed.

Combustion is chemical combination attended with the evolution of light and heat. In the ordinary combustion in lamps, fires, candles, the carbon and hydrogen of the coal, or of the oil, etc., combine with the oxygen of the air. But combustion does not necessarily involve the presence of oxygen. If either powdered antimony or a fragment of phosphorus be placed in a vessel of chlorine, it unites with chlorine, producing thereby heat and flame.

Many combustibles burn with flame. A *flame* is a gas or vapour raised to a high temperature by combustion. Its illuminating power varies with the nature of the product formed. The presence of a solid body in the flame increases the illuminating power. The flames of hydrogen, carbonic oxide, and alcohol are pale, because they only contain gaseous products of combustion. But the flames of candles, lamps, coal gas, have a high illuminating power. They owe this to the fact that the high temperature produced decomposes certain of the gases with the production of carbon, which, not being perfectly burned, becomes incandescent in the flame. Coal gas, when burnt in an arrangement by which it obtains an adequate supply of air, is almost entirely devoid of luminosity. A non-luminous flame may be made luminous by placing in it platinum wire, or asbestos. The temperature of a flame does not depend on its illuminating power. hydrogen flame, which is the palest of all flames, gives the greatest heat.

The heat produced by chemical combination of two elements may be compared to that due to the impact of bodies against each other. Thus, the action of the atoms of oxygen which, in virtue of their progressive motion and of chemical attraction, rush against ignited carbon, has been likened by Tyndall to the action of meteorites which fall into the sun.

448. **Heat disengaged during combustion.**—Many physicists, m especially Lavoisier, Rumford, Dulong, Despretz, Hess, Favre and Sil mann, and Andrews, have investigated the quantity of heat disengaged various bodies in chemical combinations.

In these experiments Lavoisier used the ice calorimeter already scribed. Rumford used a calorimeter known by his name, which cons of a rectangular copper canister filled with water. In this canister th is a worm which passes through the bottom of the box, and termin below in an inverted funnel. Under this funnel is burnt the substa experimented upon. The products of combustion, in passing through worm, heat the water of the canister, and from the increase of its t perature the quantity of heat evolved is calculated. MM. Despretz Dulong have successively modified Rumford's calorimeter by allow the combustion to take place, not outside the canister, but in a cham placed in the liquid itself; the oxygen necessary for the combustion tered by a tube in the lower part of the chamber, and the products combustion escaped by another tube placed at the upper part and twi in a serpentine form in the mass of the liquid to be heated. MM. Fa and Silbermann have improved this calorimeter very greatly (429), only by avoiding or taking account of all possible sources of error, but arranging it for the determination of the heat evolved in other chem actions than those of ordinary combustion.

The experiments of MM. Favre and Silbermann are the most tr worthy, as having been executed with the greatest care. They agree closely with those of Dulong. Taking as thermal unit the heat neces to raise the temperature of a pound of water through *one* degree Ce grade, the following table gives the thermal units in round numbers engaged by a pound of each of the substances in burning in oxygen :

Hydrogen	34462	Sulphur	
Marsh gas	13063	Anthracite	
Olefiant gas	11858	Charcoal	
Oil of turpentine	10852	Coal	
Olive oil	9860	Tallow	
Ether	9030	Diamond	
Coke	7000	Absolute alcohol	
Wood, dry	4025	Phosphorus	
Wood, moist	3100	Bisulphide of carbon	
Carbonic oxide	2400	Iron	

The experiments of Dulong, of Despretz, and of Hess prove th body in burning always produces the same quantity of heat in reac the same degree of oxidation, whether it attains this at once or reaches it after passing through intermediate stages. Thus a given we of carbon gives out the same amount of heat in burning directly to carb acid as if it were first changed into carbonic oxide, and then this b into carbonic acid.

449. **Animal heat.**—In all organs of the human body, as well as of all animals, processes of oxidation are continually going on. Oxy passes through the lungs into the blood, and so into all parts of the b In like manner the oxidisable bodies, which are principally hydrocarl

the processes of digestion into the blood, and likewise into all the body, while the products of oxidation, carbonic acid and re eliminated by the skin, the lungs, etc. Oxidation in the muscle s motion of the molecules, which are changed into contraction of cular fibres; all other oxidations produce heat directly. When y is at rest, all its functions, even involuntary motions, are trans- into heat. When the body is at work, the more vigorous oxida- the working parts are transferred to the others. Moreover, a rt of the muscular work is changed into heat, by friction of the and of the sinews in their sheaths, and of the bones in their Hence the heat produced by the body when at work is greater hen at rest. The blood distributes heat uniformly through the hich in a normal condition has a temperature of 37·5°. The blood malia has the same temperature, that of birds is somewhat higher. the temperature rises to 42°–44°, and in cholera, or when near inks to 35°.

HEATING.

Different kinds of heating.—*Heating* is the art of utilising for do- nd industrial purposes the sources of heat which nature offers to us. principal source of artificial heat is the combustion of coal, coke, od, and charcoal.

nay distinguish five kinds of heating, according to the apparatus 1st, heating with an open fire; 2nd, heating with an enclosed fire, a stove; 3rd, heating by hot air; 4th, heating by steam; 5th, by the circulation of hot water.

Fire-places.—Fire-places are open hearths built against a wall chimney, through which the products of combustion escape.

ever much they may be improved, fire-places will always remain st imperfect and costly mode of heating, for they only render le 13 per cent. of the total heat by coal or coke, and 6 per cent. by wood. This enormous loss of ature arises from the fact, that the of air necessary for combustion carries with it a large quantity of at produced, which is lost in the here. Hence it was that Franklin e-places should be adopted in cases the smallest quantity of heat was obtained from a given quantity of stible. Notwithstanding their want omy, however, they will always be ed as the healthiest and pleasantest f heating, on account of the cheer- t which they emit, and the ventila- ich they ensure.

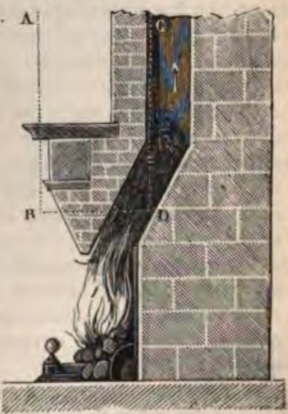


Fig. 335.

Draught of fire-places.— The of a fire is the upward current in the chimney caused by the ascent of the products of combustion; when the current is rapid and continuo the chimney is said to *draw* well.

The draught is caused by the difference between the temperature of t inside and that on the outside of the chimney; for, in consequence of th difference, the gaseous substances which fill the chimney are lighter tha the air of the room, and consequently equilibrium is impossible. Th weight of the column of gas CD, fig. 335, in the chimney being less tha that of the external column of air AB of the same height, there is a pre sure from the outside to the inside which causes the products of combu tion to ascend the more rapidly in proportion as the difference in weig of the two gaseous masses is greater.

The velocity of the draught of a chimney may be determined theoret cally by the formula

$$v=\sqrt{2g\alpha(t'-t)h},$$

in which g is the acceleration of gravity, α the coefficient of the expansi of air, h the height of the chimney, t' the mean temperature of the inside the chimney, and t the temperature of the surrounding air.

The currents caused by the difference in temperature of two commu cating gaseous masses may be demonstrated by placing a candle near t top and near the bottom of the partially-opened door of a warm roo At the top, the flame will be turned from the room towards the outsid while the contrary effect will be produced when the candle is placed the ground. The two effects are caused by the current of heated air whi issues by the top of the door, while the cold air which replaces it enters the bottom.

In order to have a good draught a chimney ought to satisfy the follo ing conditions:

i. The section of the chimney ought not to be larger than is necessa to allow an exit for the products of combustion, otherwise ascending a descending currents are produced in the chimney, which cause it to smok It is advantageous to place on the top of the chimney a conical pot na rower than the chimney, so that the smoke may escape with sufficie velocity to resist the action of the wind.

ii. The chimney ought to be sufficiently high, for, as the draught caused by the excess of the external over the internal pressure, this cess is greater in proportion as the column of heated air is longer.

iii. The external air ought to pass into the chamber with sufficie rapidity to supply the wants of the fire. In a hermetically closed roo the combustibles would not burn, or descending currents would be forme which would drive the smoke into the room. Usually air enters in suf cient quantity by the crevices of the doors and windows.

iv. Two chimneys should not communicate, for if one draws better th the other, a descending current of air is produced in the latter, which ca ries smoke with it.

453. **Stoves.**—*Stoves* are apparatus for heating with a detached fi placed in the room to be heated, so that the heat radiates in all directio round the stove. At the lower part is the draught hole by which the

ssary for combustion enters. The products of combustion escape by ns of iron chimney pipes. This mode of heating is one of the most omical, but it is by no means so healthy as that by open fire-places, he ventilation is very bad, more especially where, as in Sweden, the s are fed from the outside of the room. These stoves also emit a smell, probably arising from the decomposition of organic substances e air by their contact with the heated sides of the chimney pipes ; or ibly, as Deville and Troost's recent researches seem to show, from iffusion of gases through the heated sides of the stove.

he heating is very rapid with blackened metal stoves, but they also very rapidly. Stoves constructed of polished earthernware, which are mon on the Continent, heat more slowly, but more pleasantly, and retain the heat longer.

4. **Heating by steam.**—Steam, in condensing, gives up its latent of vaporisation, and this property has been used in heating baths, kshops, public buildings, hothouses, etc. For this purpose steam is rated in boilers similar to those used for steam-engines, and is then e to circulate in pipes placed in the room to be heated. The vapour lenses, and in doing so imparts to the pipes the latent heat, which becomes free, and thus heats the surrounding air.

5. **Heating by hot air.**—Heating by hot air consists in heating the n the lower part of a building, from whence it rises to the higher parts

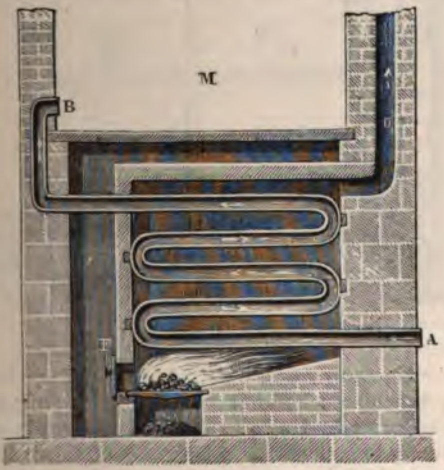


Fig. 336.

irtue of its lessened density. The apparatus is arranged as represented gure 336.

series of bent tubes, AB, only one of which is shown in the figure, is ed in a furnace, F, in the cellar. The air passes into the tubes through lower end A, where it becomes heated, and rising in the direction of

the arrows, reaches the room M by the higher aperture B. The va
rooms to be heated are provided with one or more of these aper
which are placed as low in the room as possible. The conduit O
ordinary chimney.

These apparatus are more economical than open fire-places, but
are less healthy, owing to the want of ventilation.

456. **Heating by hot water.**—This consists of a continuous circu
of water, which having been heated in a boiler, rises through a se
tubes, and then, after becoming cool, passes into the boiler again
similar series.

Figure 337 represents an apparatus for heating a building of s

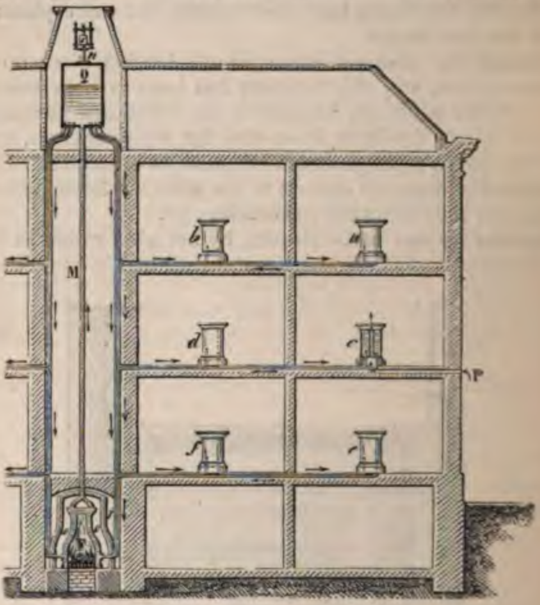


Fig. 337.

stories. The heating apparatus, which is in the cellar, consists of a
shaped boiler, *oo*, with an internal flue, F. A long pipe, M, fits i
upper part of the boiler, and also in the reservoir Q, placed in the u
part of the building to be heated. At the top of this reservoir ther
safety valve, *s*, by which the pressure of the vapour in the interior c
regulated.

The boiler, the pipe M, and a portion of the reservoir, Q, being
with water, as it becomes heated in the boiler an ascending curre
hot water rises to the reservoir Q, while at the same time desce
currents of colder and denser water pass from the lower part o
reservoir Q into receivers, *b*, *d*, *f*, filled with water. The water from

passes again through pipes into other receivers, *a*, *c*, *e*, and ultimately reaches the lower part of the boiler.

During this circulation the hot water heats the pipes and the receivers, which thus become true water stoves. The number and the dimensions of these parts are readily determined from the experimental fact that a cubic foot of water is sufficient to communicate the necessary heat to 3,200 cubic feet of air. In the interior of the receivers *a*, *b*, *c*, *d*, *e*, *f* there are cast-iron tubes which communicate with the outside by pipes, P, placed underneath the flooring. The air becomes heated in these tubes, and emerges at the upper part of the receivers.

The principal advantage of this mode of heating is that of giving a temperature which is constant for a long time; for the mass of water only cools slowly. It is much used in hothouses, baths, artificial incubation, drying rooms, and generally wherever a uniform temperature is desired.

SOURCES OF COLD.

457. **Various sources of cold.**—Besides the cold caused by the passage of a body from the solid to the liquid state, of which we have already spoken, cold is produced by the expansion of gases, by radiation in general, and more especially by nocturnal radiation.

458. **Cold produced by the expansion of gases. Ice machines.**—We have seen that when a gas is compressed, the temperature rises. The reverse of this is also the case: when a gas is rarefied a reduction of temperature ensues, because a quantity of sensible heat disappears when the gas becomes increased to a larger volume. This may be shown by placing a delicate Breguet's thermometer under the receiver of an air-pump, and exhausting; at each stroke of the piston the needle moves in the direction of zero, and regains its original temperature when air is admitted. Kirk has invented a machine for the manufacture of ice, which depends on this property. The heat developed by the compression of air is removed by a current of cold water; the vessel containing the compressed air being placed in brine, the air is allowed to expand; in so doing it cools the brine so considerably as to freeze water contained in vessels placed in the brine. It is stated that by this means a ton of coals (used in working a steam-engine by which the compression is effected) can produce a ton of ice.

459. **Cold produced by nocturnal radiation.**—During the day, the ground receives from the sun more heat than radiates into space, and the temperature rises. The reverse is the case during night. The heat which the earth loses by radiation is no longer compensated for, and consequently a fall of temperature takes place, which is greater according as the sky is clearer, for clouds send towards the earth rays of greater intensity than those which come from the celestial spaces. In some winters it has been found that rivers have not frozen, the sky having been cloudy, although the thermometer has been for several days below $-4°$; while in other less severe winters the rivers freeze when the sky is clear. The emissive

power exercises a great influence on the cold produced by radiation; th greater it is the greater is the cold.

In Bengal, the nocturnal cooling is used in manufacturing ice. Lar flat vessels containing water are placed on non-conducting substanc such as straw or dry leaves. In consequence of the radiation the wat freezes, even when the temperature of the air is 10° C. The same metho can be applied in all cases with a clear sky.

It is said that the Peruvians, in order to preserve the shoots of youn plants from freezing, light great fires in their neighbourhood, the smok of which, producing an artificial cloud, hinders the cooling produced b radiation.

460. **Absolute zero of temperature.**—As a gas is increased $\frac{1}{273}$ of it volume for each degree Centigrade, it follows that at a temperature o 273° C. the volume of any gas measured at zero is doubled. In lik manner, if the temperature of a given volume at zero were lowered throug −273°, the contraction would be equal to the volume; that is, the volum would not exist.

At this temperature the motion of the molecules of the gas would completely cease, and the pressure thereby occasioned. In all pro bability, before reaching this temperature, gases would undergo some change.

This point on the Centigrade scale is called the *absolute zero of te perature*; the temperatures reckoned from this point are called *absolut temperatures.* They are clearly obtained by adding 273 to the temperature on the Centigrade scale.

CHAPTER XII.

MECHANICAL EQUIVALENT OF HEAT.

461. **Mechanical equivalent of heat.**—If the various instances of the production of heat by motion be examined, it will be found that in all cases mechanical force is consumed. Thus, in rubbing two bodies against each other, motion is apparently destroyed by friction; it is not, howeve lost, but appears in the form of a motion of the particles of the body the motion of the mass is transformed into a motion of the molecules.

Again, if a body be allowed to fall from a height, it strikes against the ground with a certain velocity. According to older views, its motion is destroyed, *vis viva* is lost. This, however, is not the case; the *vis viv* of the body appears as *vis viva* of its molecules.

In the case, too, of chemical action, the most productive artificial source of heat, it is not difficult to conceive that there is in the act of combinin an impact of the dissimilar molecules against each other, an effect analogous to the production of heat by the impact of masses of matte against each other.

In like manner, heat may be made to produce motion, as in the case of the steam-engine, the propulsion of shot from a gun.

Traces of a view that there is a connection between heat and motion are to be met with in the older writers, Bacon, for example; and Locke says: 'Heat is a very brisk agitation of the insensible parts of the object, which produces in us that sensation from whence we denominate the object hot; so that what in our sensation is heat, in the object is nothing but motion.' Rumford, in explaining his great experiment of the production of heat by friction, was unable to assign any other cause for the heat produced than motion; and Davy, in the explanation of his experiment of melting ice by friction *in vacuo*, expressed similar views. Carnot, in a work on the steam-engine, published in 1824, also indicated a connection between heat and work.

The views, however, which had been stated by isolated writers had little or no influence on the progress of scientific investigation, and it is in the year 1842 that the modern theories may be said to have had their origin. In that year Dr. Mayer, a physician in Heilbronn, formally stated that there exists a connection between heat and work; and he it was who first introduced into science the expression '*mechanical equivalent of heat.*' Mayer also gave a method by which this equivalent could be calculated; the particular results, however, are of no value, as the method, though correct in principle, is founded on incorrect data.

In the same year, too, Colding of Copenhagen published experiments on the production of heat by friction, from which he concluded that the evolution of heat was proportional to the mechanical energy expended.

About the same time as Mayer, but quite independently of him, Joule commenced a series of experimental investigations on the relation between heat and work. These first drew the attention of scientific men to the subject, and were admitted as a proof that the transformation of heat into mechanical energy, or of mechanical energy into heat, always takes place in a definite numerical ratio.

Subsequently to Mayer and Joule, several physicists by their theoretical and experimental investigations have contributed to establish the mechanical theory of heat, namely, in this country, Sir W. Thomson and Rankine; in Germany, Helmholtz, Clausius, and Holtzmann; and in France, Clapeyron and Regnault.

The following are some of the most important and satisfactory of Joule's experiments.

A copper vessel, B (fig. 338), was provided with a brass paddle-wheel (indicated by the dotted lines), which could be made to rotate about a vertical axis. Two weights, E and F, were attached to cords which passed over the pulleys C and D, and were connected with the axis A. These weights in falling caused the wheel to rotate. The height of the fall, which in Joule's experiments was about 63 feet, was indicated on the scales G and H. The roller A was so constructed that by detaching a pin the weights could be raised without moving the wheel. The vessel B was filled with water and placed on a stand, and the weights allowed to sink. When they had reached the ground, the roller was detached from [illegible] the weights again raised, the same operations being repea [illegible] heat produced was measured by ordinary calorime [illegible]

[illegible] expended is measured by the product of the weight into [illegible] which it falls, or *wh*, less the labour lost by the frictio [illegible] This is diminished as far as possible by the use of fric [illegible] its amount is determined by connecting C and D without c [illegible] pass over A, and then determining the weight necessar [illegible] them a uniform motion.

[illegible] has been found that a thermal unit—that is, the quar [illegible] which a pound of water is raised through 1° C.—is gener [illegible] expenditure of the same amount of work as would be require [illegible] pounds through 1 foot, or 1 pound through 1392 feet. Th

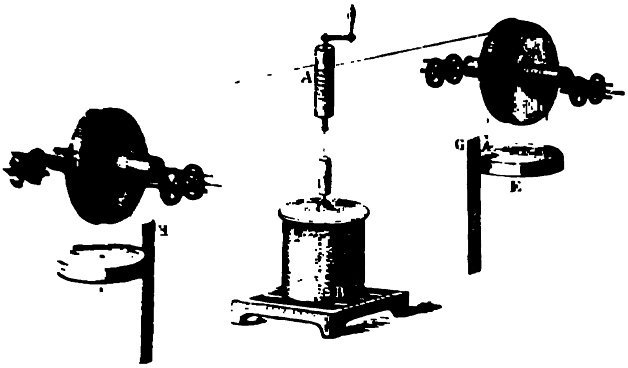


Fig. 338.

[illegible] the mechanical equivalent of the thermal [illegible] paddle-wheel in mercury gave 1397 foot-pou [illegible] two iron plates gave 1395 foot-pounds, as [illegible] one thermal unit.

[illegible] experiments, the air in a receiver was compre [illegible] both being immersed in a known weigh [illegible] temperature. After 300 strokes of the piston, the h [illegible] the water had gained. This heat was due to [illegible] to the friction of the piston. To eliminate [illegible] ment was made under the same conditions, [illegible] The air was not compressed, and 300 str [illegible] thermal units. Hence C – C′ is the heat [illegible] the gas. Representing the foot-pounds [illegible] heat by W, we have $\frac{W}{C-C'}$ for the value of [illegible] By this method Joule obtained the num he mean number which Joule adopted for the mechanical equivalent ne thermal unit on the Centigrade scale is 1390 foot-pounds; on the renheit scale it is 772 foot-pounds. This number is called *Joule's ivalent.*

. Hirn has made the following determination of the mechanical equi- nt by means of the heat produced by the compression of lead. A e block of sandstone, CD (fig. 339), is suspended vertically by cords

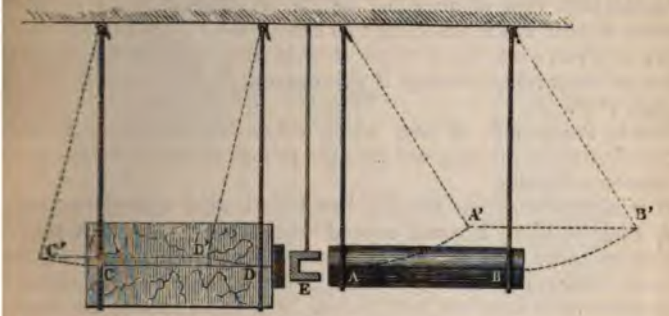


Fig. 339.

eight is P. E is a piece of lead, fashioned so that its temperature be determined by the introduction of a thermometer. The weight of is π, and its specific heat c. AB is a cylinder of cast iron, whose ht is p. If this be raised to A_1B_1, a height of h, and allowed to fall n, it compresses the lead, E, against the anvil, CD. It remains to sure on the one hand the work lost, and on the other the heat gained. he hammer AB being raised to a height h, the work of its fall is ph. as, by its elasticity, it rises again to a height h_1 the work is $p\ (h-h_1)$. anvil, CD, on the other hand, has been raised to a height H, and absorbed in so doing PH units of work. The work, T, definitely ab- ed by the lead is $p\ (h-h)-\text{PH}$. On the other hand, the lead has been ed by θ, it has gained $\pi c \theta$ thermal units, and the mechanical equivalent ual to the quotient $\frac{\text{T}}{\pi c \theta}$. A series of six experiments gave 1394 as mechanical equivalent.

he following is the method which Mayer employed in calculating the hanical equivalent of heat. It is taken, with slight modifications, from Tyndall's work on 'Heat,' who, while strictly following Mayer's rea- ng, has corrected his data.

t us suppose that a rectangular vessel with a section of a square contains at 0° a cubic foot of air under the ordinary atmospheric ure; and let us suppose that it is enclosed by a piston without ht.

ppose now that the cubic foot of air is heated until its volume is led: from the coefficient of expansion of air we know that this is the at 273° C. The gas in doubling its volume will have raised the piston through a foot in height; it will have lifted the atmospheric pressure through this distance. But the atmospheric pressure on a square foot is in round numbers 15 × 144 = 2160 pounds. Hence a cubic foot of air in doubling its volume has lifted a weight of 2160 pounds through a height of a foot.

Now a cubic foot of air at zero weighs 1·29 ounce, and the specific heat of air under constant pressure, that is, when it can expand freely, as compared with that of an equal weight of water, is 0·24; so that the quantity of heat which will raise 1·29 ounce of air through 273° will only raise 0·24 × 1·29 = 0·31 oz. of water through the same temperature; but 0·31 oz. of water raised through 273° is equal to 5·29 pounds of water raised through 1° C.

That is, the quantity of heat which will double the volume of a cubic foot of air, and in so doing will lift 2160 pounds through a height of a foot, is 5·29 thermal units.

Now in the above case the gas has been heated under constant pressure, that is, when it could expand freely. If, however, it had been heated under constant volume, its specific heat would have been less in the ratio 1 : 1·414 (418), so that the quantity of heat required under these circumstances to raise the temperature of a cubic foot of air would be $5{\cdot}29 \times \frac{1}{1{\cdot}41} = 3{\cdot}74$. Deducting this from 5·29, the difference 1·55 represents the weight of water which would have been raised 1° C. by the excess of heat imparted to the air when it could expand freely. But this excess has been consumed in the work of raising 2160 pounds through a foot. Dividing this by 1·55 we have 1393. Hence the heat which will raise a pound of water through 1° C. will raise a weight of 1393 pounds through a height of a foot; a numerical value of the mechanical equivalent of heat agreeing as closely as can be expected with that which Joule adopted as the most certain of his experimental results.

The law of the relation of heat to mechanical energy may thus be stated: *Heat and mechanical energy are mutually convertible; and heat requires for its production, and produces by its disappearance, mechanical energy in the ratio of* 1390 *foot-pounds for every thermal unit.*

A variety of experiments may in like manner be adduced to show that whenever heat disappears work is produced. For example, if in a reservoir immersed in water the air be compressed to the extent of 10 atmospheres: supposing that now, when the compressed air has acquired the temperature of the water, it be allowed to act upon a piston loaded by a weight, the weight is raised. At the same time the water becomes cooler, showing that a certain quantity of heat had disappeared in producing the mechanical effort of raising the weight.

This may also be illustrated by the following experiment, due to Prof. Tyndall.

A strong metal box is taken, provided with a stopcock, on which can be screwed a small condensing pump. Having compressed the air by its means, as it becomes heated by this process, the box is allowed to stand for some time, until it has acquired the temperature of the surrounding edium. On opening the stopcock, the air rushes out; it is expelled by e expansive force of the internal air; in short, the air drives itself out. Work is therefore performed by the gas, and there should be a disap-

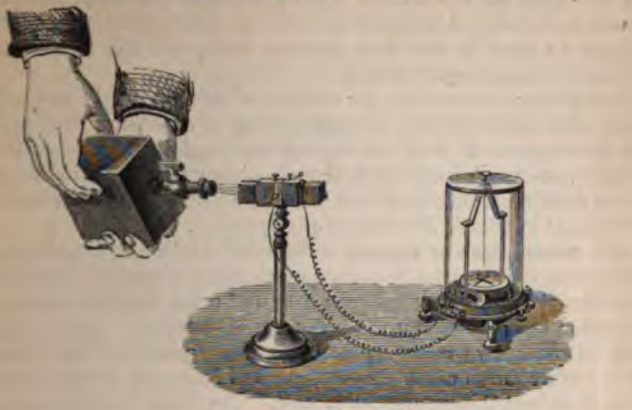


Fig. 340.

earance of heat; and if the jet of gas be allowed to strike against the hermo-pile, the galvanometer is deflected, and the direction of its deflecion indicates a cooling (fig. 340).

If, on the contrary, the experiment is made with an ordinary pair of

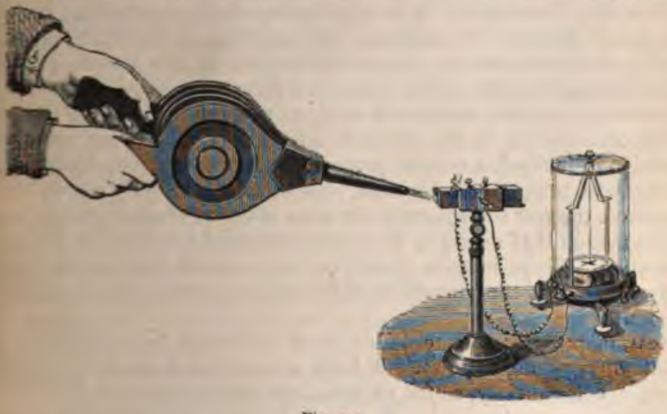


Fig. 341.

ellows, and the current of air is allowed to strike against the battery, the eflection of the galvanometer is in the opposite direction, indicating an ncrease of temperature (fig. 341). In this case the hand of the experimener performs the work, which is converted into heat.

Joule placed in a calorimeter two equal copper reservoirs, which could be connected by a tube. One of these contained air at 22 atmospheres, the other was exhausted. When they were connected, they came into equilibrium under a pressure of 11 atmospheres; but as the gas in expanding had done no work, there was no alteration in temperature. When, however, the second reservoir was full of water, the air in entering was obliged to expel it and thus perform work, and the temperature sank, owing to an absorption of heat.

For further information the student of this subject is strongly recommended to read Professor Tyndall's *Heat as a Mode of Motion*, in which the phenomena of heat are throughout explained in accordance with modern views. A condensed, though complete and systematic, account of the dynamical theory of heat is met with in Professor Foster's articles on 'Heat,' in Watt's *Dictionary of Chemistry*.

462. **Dissipation of Energy.**—Rankine has the following interesting observations on a remarkable consequence of the mutual convertibility which has been shown to exist between heat and other forms of energy. Sir W. Thomson has pointed out the fact, that there exists at least in the present state of the known world a predominating tendency to the conversion of all the other forms of physical energy into heat, and to the uniform diffusion of all heat throughout all matter. The form in which we generally find energy originally collected is that of a store of chemical power consisting of uncombined elements. The combination of these elements produces energy in the form known by the name of electrical currents, part only of which can be employed in analysing chemical compounds, and thus reconverted into a store of chemical power; the remainder is necessarily converted into heat; a part only of this heat can be employed in analysing compounds or in reproducing electric currents. If the remainder of the heat be employed in expanding an elastic substance, it may be converted entirely into visible motion, or into a store of visible mechanical power, (by raising weights, for example) provided the elastic substance is enabled to expand until its temperature falls to the point which corresponds to the absolute privation of heat; but unless this condition is fulfilled, a certain proportion only of the heat, depending on the range of temperature through which the elastic body works, can be converted, the rest remaining in the state of heat. On the other hand, all visible motion is of necessity ultimately converted into heat by the agency of friction. There is then in the present state of the known world, a tendency towards the conversion of all physical energy into the sole form of heat.

Heat, moreover, tends to diffuse itself uniformly by conduction and radiation, until all matter shall have acquired the same temperature. There is, consequently, so far as we understand the present condition of the universe, a tendency towards a state in which all physical energy will be in the state of heat, and that heat so diffused, that all matter will be at the same temperature; so that there will be an end of all physical phenomena.

Vast as this speculation may seem, it appears to be soundly based on experimental data, and to truly represent the present condition of the universe as far as we know it.

BOOK VII.

ON LIGHT.

CHAPTER I.

TRANSMISSION, VELOCITY, AND INTENSITY OF LIGHT.

63. **Theories of light.**—*Light* is the agent which, by its action on
retina, excites in us the sensation of vision. That part of physics
ich deals with the properties of light is known as *optics*.

n order to explain the origin of light, various hypotheses have been
de, the most important of which are the *emission* or *corpuscular* theory,
l the *undulatory* theory.

On the *emission* theory it is assumed that luminous bodies emit, in all
ections, an imponderable substance, which consists of molecules of an
reme degree of tenuity : these are propagated in right lines with an
ost infinite velocity. Penetrating into the eye they act on the retina,
d determine the sensation which constitutes vision.

On the undulatory theory, all bodies, as well as the celestial spaces, are
ed by an extremely subtle elastic medium, which is called the *lumi-*
ferous ether. The luminosity of a body is due to an infinitely rapid
ratory motion of its molecules, which, when communicated to the
er, is propagated in all directions in the form of spherical waves, and
vibratory motion, being thus transmitted to the retina, calls forth the
sation of vision. The vibrations of the ether take place not in the
ection of the wave, but in a plane at right angles to it. The latter are
lled the *transversal* vibrations. An idea of these may be formed by
aking a rope at one end. The vibrations, or to and fro movements, of
particles of the rope, are at right angles to the length of the rope, but
onward motion of the wave's form is in the direction of the length of
rope.

On the emission theory the propagation of light is effected by a motion
translation of particles of light thrown out from the luminous body,
a bullet is discharged from a gun ; on the undulatory theory there is
progressive motion of the particles themselves, but only of the state
disturbance which was communicated by the luminous body; it is a
tion of *oscillation*, and, like the propagation of waves in water, takes
ce by a series of vibrations.

The luminiferous ether penetrates all bodies, but on account of its extreme tenuity it is uninfluenced by gravitation ; it occupies space, an although it presents no appreciable resistance to the motion of the dense bodies, it is possible that it hinders the motion of the smaller comet It has been found, for example, that Encke's comet, whose period of rev lution is about 3½ years, has its period diminished by about 0·11 of a d at each successive rotation, and this diminution is ascribed by some to th resistance of the ether.

The fundamental principles of the undulatory theory were enunciate by Huyghens, and subsequently by Euler. The emission theory, prin cipally owing to Newton's powerful support, was for long the prevalen scientific creed. The undulatory theory was adopted and advocated b Young, who showed how a large number of optical phenomena, particularl those of diffraction, were to be explained by that theory. Subsequently t though independently of, Young, Fresnel showed that the phenomena o diffraction, and also those of polarisation, are explicable on the sam theory, which, since his time, has been generally accepted.

The undulatory theory not only explains the phenomena of light, but i reveals an intimate connection between these phenomena and those of heat it shows, also, how completely analogous the phenomena of light are t those of sound, regard being had to the differences of the media in whic these two classes of phenomena take place.

464. **Luminous, transparent, translucent, and opaque bodies.**— *Luminous* bodies are those which emit light, such as the sun, and ignite bodies. *Transparent* or *diaphanous* bodies are those which readily trans mit light, and through which objects can be distinguished ; water, gase polished glass, are of this kind. *Translucent* bodies transmit light, bu objects cannot be distinguished through them: ground glass, oiled pape etc., belong to this class. *Opaque* bodies do not transmit light ; for ex- ample, wood, metals, etc. No bodies are quite opaque ; they are all mor or less translucent when cut in sufficiently thin leaves.

Foucault has recently shown that when the object glass of a telescop is thinly silvered, the layer is so transparent, that the sun can be viewe through it without danger to the eyes, since the metallic surface reflects the greater part of the heat and light.

465. **Luminous ray and pencil.**—A *luminous ray* is the line in which light is propagated ; a *luminous pencil* is a collection of rays from the same source ; it is said to be *parallel* when it is composed of parallel rays, *divergent* when the rays separate from each other, and *convergent* when they tend towards the same point. Every luminous body emits divergent rectilinear rays from all its points, and in all directions.

466. **Propagation of light in a homogeneous medium.**—A *medium* is any space or substance which light can traverse, such as a vacuum, air, water, glass, etc. A medium is said to be homogeneous when its chemical composition and density are the same in all parts.

In every homogeneous medium light is propagated in a right line. For, if an opaque body is placed in the right line which joins the eye and the luminous body, the light is intercepted. The light which passes into a dark room by a small aperture, leaves a luminous trace, which i ible from the light falling on the particles suspended in the atmo- here.

Light changes its direction on meeting an object which it cannot pene- te, or when it passes from one medium to another. These phenomena l be described under the heads *reflection* and *refraction*.

67. **Shadow, penumbra.**—When light falls upon an opaque body it nnot penetrate into the space immediately behind it, and this space is led the *shadow*.

In determining the extent and the shape of a shadow projected by a dy, two cases are to be distinguished: that in which the luminous rce is a single point, and that in which it is a body of any given ent.

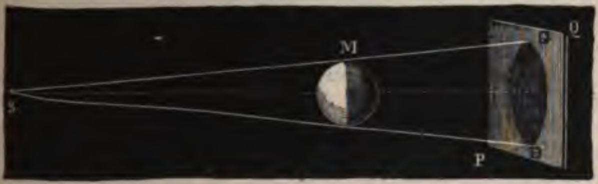


Fig. 342.

n the first case, let S (fig. 342) be the luminous point, and M a spherical ly, which causes the shadow. If an infinitely long straight line, SG, ve round the sphere M tangentially, always passing through the point his line will produce a conical surface, which, beyond the sphere, sepa- es that portion of space which is in shadow from that which is illuminated. the present case, on placing behind the opaque body a screen, PQ, the it of the shadow HG will be sharply defined. This is not, however, ally the case, for luminous bodies have always a certain magnitude, and not merely luminous points.

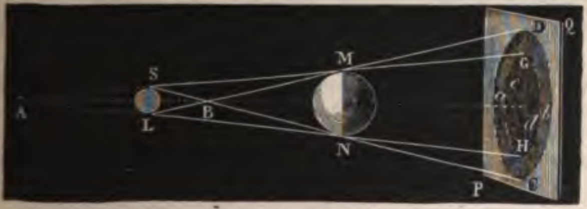


Fig. 343.

uppose that the luminous and illuminated bodies are two spheres, SL MN (fig. 343). If an infinite straight line, AG, moves tangentially to h spheres, always cutting the line of the centre in the point A, it will duce a conical surface with this point for a summit, and which traces und the sphere MN a perfectly dark space, MGHN. If a second right , LD, which cuts the line of centre in B, moves tangentially to the two eres, so as to produce a new conical surface, BDC, it will be seen that

all the space outside this surface is illuminated, but that the part betv
the two conical surfaces is neither quite dark nor quite light. So that
screen, PQ, is placed behind the opaque body, the portion *c*G*d*H of
screen is quite in the shadow, while the space *ab* receives light from
tain parts of the luminous body, and not from others. It is brighter t
the true shadow, and not so bright as the rest of the screen, and it is
cordingly called the *penumbra.*

Shadows such as these are *geometrical shadows; physical shadow*
those which are really seen, are by no means so sharply defined. A
tain quantity of light passes into the shadow, even when the source of l
is a mere point, and conversely the shadow influences the illuminated p
This phenomenon, which will be afterwards described, is known by
name of *diffraction.*

468. **Images produced by small apertures.**—When luminous r
which pass into a dark chamber *through a small aperture*, are rece
upon a screen, they form images of external objects. These images
inverted; their shape is always that of the external objects, and is i
pendent of the shape of the aperture.

The inversion of the images arises from the fact that the luminous
proceeding from external objects, and penetrating into the cham
cross one another in passing the aperture, as shown in fig. 344. C

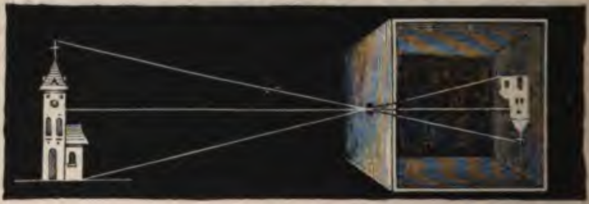


Fig. 344.

tinuing in a straight line, the rays from the higher parts meet the sc
at the lower parts, and inversely, those which come from the lower p
meet the higher parts of the screen. Hence the inversion of the ima
In the article *Camera obscura*, it will be seen how the brightness and p
cision of the images are increased by means of lenses.

In order to show that the shape of the image is independent of tha
the aperture, when the latter is sufficiently small, and the screen at
adequate distance, imagine a triangular aperture, O (fig. 345), made in
door of a dark chamber, and let *ab* be a screen on which is received
image of a flame, AB. A divergent pencil from each point of the fla
penetrates through the aperture, and forms on the screen a triang
image resembling the aperture. But the union of all these partial ima
produces a total image of the same form as the luminous object. Fo
we conceive that an infinite straight line moves round the aperture, v
the condition that it is always tangential to the luminous object AB,
that the aperture is very small, the straight line describes two cones,

x of which is the aperture, while one of the bases is the luminous ob-
t, and the other the luminous object on the screen—that is, the image.
nce, if the screen is perpendicular to the right line joining the centre of

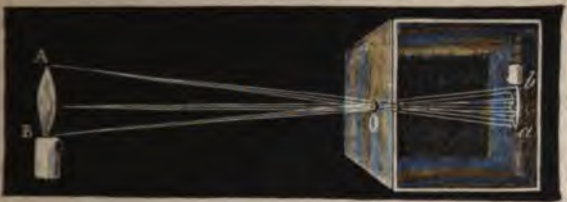


Fig. 345.

aperture and the centre of the luminous body, the image is similar to
body; but if the screen is oblique, the image is elongated in the direc-
of its obliquity. This is what is seen in the shadow produced by
age; the luminous rays passing through the leaves produce images
he sun, which are either round or elliptical, according as the ground
erpendicular or oblique to the solar rays, and this is the case whatever
the shape of the aperture through which the light passes.

69. **Velocity of light.**—Light moves with such a velocity that at the
face of the earth there is, to ordinary observation, no appreciable in-
al between the occurrence of any luminous phenomenon and its per-
tion by the eye. And accordingly, this velocity was first determined
means of astronomical observations. Römer, a Danish astronomer, in
5, first deduced the velocity of light from an observation of the
pses of Jupiter's first satellite.

upiter is a planet, round which four satellites revolve as the moon does
nd the earth. This first satellite, E (fig. 346), suffers occultation—that

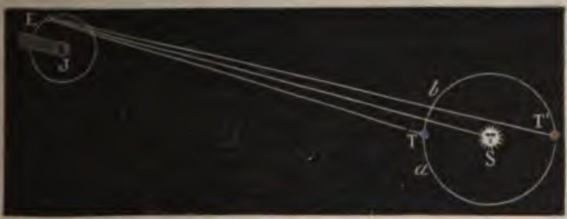


Fig. 346

passes into Jupiter's shadow—at equal intervals of time, which are
28m. 36s. While the earth moves in that part of its orbit, *ab*, nearest
iter, its distance from that planet does not materially alter, and the
rvals between two successive occultations of the satellite are approxi-
ely the same; but in proportion as the earth moves away in its revo-
n round the sun, S, the interval between two occultations increases,
when, at the end of six months, the earth has passed from the position

T to the position T′, a *total* retardation of 16m. 36s. is observed betwe the time at which the phenomenon is seen and that at which it is calc lated to take place. But when the earth was in the position T, the su light reflected from the satellite E had to traverse the distance ET, whi in the second position the light had to traverse the distance ET′. Th distance exceeds the first by the quantity TT′, for from the great distan of the satellite E, the rays ET and ET′ may be considered parallel. Co sequently, light requires 16m. 36s. to travel the diameter TT′ of the te restrial orbit, or twice the distance of the earth from the sun, which giv for its velocity 190,000 miles in a second.

The stars nearest the earth are separated from it by at least 206,2 times the distance of the sun. Consequently, the light which they sen requires 3¼ years to reach us. Those stars, which are only visible by mean of the telescope, are possibly at such a distance that thousands of yea would be required for their light to reach our planetary system. Th might have been extinguished for years without our knowing it.

470. **Foucault's apparatus for determining the velocity of light.**- Notwithstanding the prodigious velocity of light, M. Foucault has suc ceeded in determining it experimentally by the aid of an ingenious app ratus, based on the use of the rotating mirror, which has been adopted b Mr. Wheatstone in measuring the velocity of electricity.

In the description of this apparatus, a knowledge of the principal pr perties of mirrors and of lenses is presupposed. Figure 347 represents t

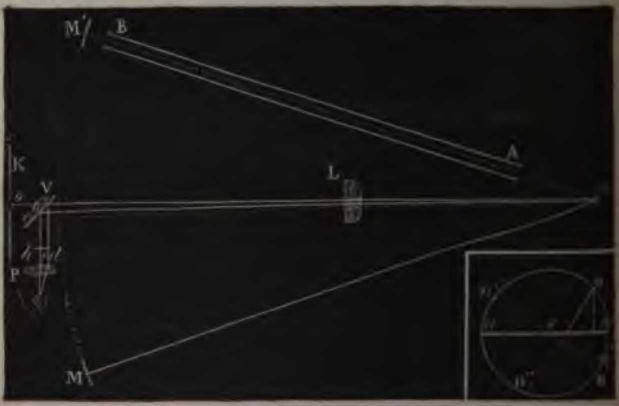


Fig. 347. Fig. 348.

principal parts of M. Foucault's arrangement. The window shutter, K, a dark chamber is perforated by a square aperture, behind which a platinu wire, *o*, is stretched vertically. A beam of solar light reflected from t outside upon a mirror enters the dark room by the square aperture, me the platinum wire, and then traverses an achromatic lens, L, with a lo focus, placed at a distance from the platinum wire less than double t principal focal distance. The image of the platinum wire, more or less magnified, would thus be formed on the axis of the lens; but the luminous pencil having traversed the lens, impinges on a plane mirror, m, rotating with great velocity; it is reflected from this, and forms in space an image of the platinum wire, which is displaced with an angular velocity double that of the mirror.* This image is reflected by a concave mirror, M, whose centre of curvature coincides with the axis of rotation of the mirror m, and with its centre of figure. The pencil reflected from the mirror M returns upon itself, is again reflected from the mirror m, traverses the lens a second time, and forms an image of the platinum wire, which appears on the wire itself so long as the mirror m turns slowly.

In order to see this image without hiding the pencil which enters by the aperture K, a mirror of unsilvered glass, V, with parallel faces, is placed between the lens and the wire, and is inclined so that the reflected rays fall upon a powerful eyepiece, P.

The apparatus being arranged, if the mirror m is at rest, the ray after meeting M is reflected to m, and from thence returns along its former path, till it meets the glass plate V in a, and being partially reflected, forms at d—the distance ad being equal to ao—an image of the wire, which the eye is enabled to observe by means of the eyepiece P. If the mirror, instead of being fixed, is moving slowly round—its axis being at right angles to the plane of the paper—there will be no sensible change in the position of the mirror m during the brief interval elapsing while light travels from m to M and back again, but the image will alternately disappear and reappear. If now the velocity of m is increased to upwards of 30 turns per second, the interval between the disappearance and reappearance is so short that the impression on the eye is persistent, and the image appears perfectly steady.

Lastly, if the mirror turns with sufficient velocity, there is an appreciable change in its position during the time which the light takes in making the double journey from m to M, and from M to m; the return ray, after its reflection from the mirror m, takes the direction mb, and forms its image at i; that is, the image has undergone a total deviation, di. Speaking precisely, there is a deviation as soon as the mirror turns, even slowly, but it is only appreciable when it has acquired a certain magnitude, which is the case when the velocity of rotation is sufficiently rapid, or the distance Mm sufficiently great, for the deviation necessarily increases with the time which the light takes in returning on its own path.

In M. Foucault's experiment the distance Mm was only 13½ feet; when the mirror rotated with a velocity of 600 to 800 turns in a second, deviations of $\frac{2}{10}$ to $\frac{3}{10}$ of a millimeter were obtained.

If $\mathrm{M}m = l$, $\mathrm{L}m = l'$, $o\mathrm{L} = r$, and representing by n the number of turns in a second, by δ the absolute deviation *di*, and by V the velocity of light M. Foucault arrived at the formula

---

* To prove this, let mn (fig. 360) be the rotating mirror, O a fixed object placed in front, and forming its image at O′. When the mirror comes into the position $m'n'$, the image is formed at O″. But the arc O′m equals the arc Om, and the arc O″m' = the arc Om'; hence the arcs OO′, OO″, are respectively double the arc Om, &c. Therefore, by subtraction, the arc O′O″ is double the arc mm', or the angular velocity of the image is double that of the mirror.

$$V = \frac{8\pi l^2 nr}{\delta(l + l')},$$

from which the velocity of light is calculated at 185,157 miles in a second; this number, which is less than that ordinarily assumed, agrees remarkably well with the value deduced from the new determinations of the value of the solar parallax.

In this apparatus liquids can be experimented upon. For that purpose a tube, AB, 10 feet long, and filled with distilled water, is placed between the turning mirror *m*, and a concave mirror M′, identical with the mirror M. The luminous rays reflected by the rotating mirror, in the direction *m*M′, traverse the column of water AB twice before returning to V. But the return ray then becomes reflected at *c*, and forms its image at *h*; the deviation is consequently greater for rays which have traversed water than for those which have passed through air alone; hence the velocity of light is less in water than in air.

This is the most important part of these experiments. For it had been shown theoretically that on the undulatory theory the velocity of light must be less in the more highly refracting medium, while the very opposite is a necessary consequence of the emission theory. Hence Foucault's result may be regarded as a crucial test of the validity of the undulatory theory.

The mechanism which M. Foucault uses to turn the mirror with great velocity consists of a small steam turbine, bearing a sort of resemblance to the syren, and, like that instrument, giving a higher sound as the rotation is more rapid; in fact, it is by the pitch of the note that the velocity of the rotation is determined.

471. **Experiments of M. Fizeau.**—In 1849 M. Fizeau measured directly the velocity of light, by ascertaining the time it took to travel from Suresnes to Montmartre and back again. The apparatus employed was a toothed wheel, capable of being turned more or less quickly, and with a velocity that could be exactly ascertained. The teeth were made of precisely the same width as the intervals between them. The apparatus being placed at Suresnes, a pencil of parallel rays was transmitted through an interval between two teeth to a mirror placed at Montmartre. The pencil, directed by a properly-arranged system of tubes and lenses, returned to the wheel. As long as the apparatus was at rest the pencil returned exactly through the same interval as that through which it first set out. But when the wheel was turned sufficiently fast, a tooth was made to take the place of an interval, and the ray was intercepted. By causing the wheel to turn more rapidly, it reappeared when the interval between the next two teeth had taken the place of the former tooth at the instant of the return of the pencil.

The distance between the two stations was 28,334 ft. By means of the data furnished by this distance, by the dimensions of the wheel, its velocity of rotation, etc., M. Fizeau found the velocity of light to be

,000 miles per second, a result agreeing with that given by astronomi- observation as closely as can be expected in a determination of this d.

72. **Laws of the intensity of light.**—The *intensity* of illumination he quantity of light received on the unit of surface; it is subject to the owing laws :—

. *The intensity of illumination on a given surface is inversely as the are of its distance from the source of light.*

I. *The intensity of illumination which is received obliquely is propor- nal to the cosine of the angle which the luminous rays make with the mal to the illuminated surface.*

n order to demonstrate the first law, let there be two circular screens, and AB (fig. 349), one placed at a certain distance from a source of t, L, and the other at double this distance, and let s and S be the

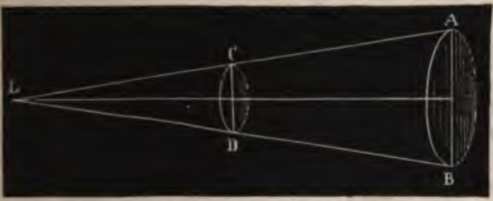


Fig. 349.

s of the two screens. If a be the total quantity of light which is tted by the source in the direction of the cone ALB, the intensity of light on the screen CD, that is, the quantity which falls on the unit urface is $\frac{a}{s}$, and the intensity on the screen AB is $\frac{a}{S}$. Now, as the ngles ALB and CLD are similar, the diameter of AB is double that of ; and as the surfaces of circles are as the squares of their diameters, surface S is four times s, consequently the intensity $\frac{a}{S}$ is one-fourth $\frac{a}{s}$.

he same law may also be demonstrated by an experiment with the aratus represented in fig. 351. It is made by comparing the shadows n opaque rod cast upon a glass plate, in one case by the light of a le candle, and in another by that of four candles, placed at double distance of the first. In both cases the shadows have the same nsity.

igure 349 shows that it is owing to the divergence of the luminous emitted from the same source that the intensity of light is inversely he square of the distance. The illumination of a surface placed in a n of parallel luminous rays is the same at all distances, at any rate in cuum, for in air and in other transparent media the intensity of light eases in consequence of absorption, but far more slowly than the re of the distance

The second law of intensity corresponds to the law which we found to prevail for heat : it may be theoretically deduced as follow

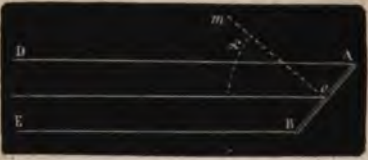


Fig. 350.

DA, EB (fig. 350) be a of parallel rays falling obli on a surface, AB, and let the normal to this surfac S is the section of the a the total quantity of which falls on the surface and I that which falls on th of surface (that is, the intens illumination), we have $I = \frac{a}{AB}$. But as S is only the projection of A a plane perpendicular to the pencil, we know from trigonometry tha AB cos α, from which $AB = \frac{S}{\cos \alpha}$. This value, substituted in the equation, gives $I = \frac{a}{S} \cos \alpha$, a formula which demonstrates the law cosine, for as a and S are constant quantities, I is proportional to c

The law of the cosine applies also to rays emitted obliquely by a nous surface ; that is, the rays are less intense in proportion as th more inclined to the surface which emits them. In this respect the respond to the third law of the intensity of radiant heat.

473. **Photometers.**—A *photometer* is an apparatus for measuri relative intensities of light.

Rumford's photometer. This consists of a ground glass screen, in of which is fixed an opaque rod (fig. 351) ; the lights to be compare

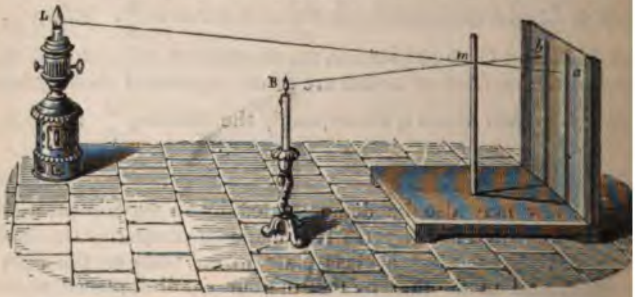


Fig. 351.

instance, a lamp and a candle—are placed at a certain distance in manner that each projects on the screen a shadow of the rod. shadows thus projected are at first of unequal intensity, but by al the position of the lamp, it may be so placed that the intensity of th shadows is the same. Then, since the shadow thrown by the la illuminated by the candle, and that thrown by the candle is illumi by the lamp, the illumination of the screen due to each light is the tensities of the two lights, that is, the illuminations which they give at equal distances, are then directly proportional to the squares r distances from the shadows; that is to say, that if the lamp is times the distance of the candle, its illuminating power is nine as great.

if i and i' are the intensities of the lamp and the candle at the unit ance, and d and d' their distances from the shadows, it follows, he first law of the intensity of light, that the intensity of the lamp distance d is $\frac{i}{d^2}$, and that of the candle $\frac{i'}{d'^2}$ at the distance d'. On reen these two intensities are equal; hence $\frac{i}{d^2}=\frac{i'}{d'^2}$, or $\frac{i}{i'}=\frac{d^2}{d'^2}$, was to be proved.

sen's photometer.—When a grease spot is made on a piece of bibu- aper, the part appears translucent. If the paper be illuminated by t placed in front, the spot appears darker than the surrounding if, on the contrary, it be illuminated from behind, the spot appears n a dark ground. If the greased part and the rest appear un- ed, the intensity of illumination on both sides is the same. Bunsen's neter depends on an application of this principle. A circular spot le on a paper screen by means of a solution of spermaceti in naph- behind this is placed a light of a certain intensity, which serves as a ird; in this country it is usually a wax candle of known dimensions. ght to be tested is then moved in a right line to such a distance in f the diaphragm that there is no difference in brightness between eased part and the rest of the screen. By measuring the distances lights from the screen, their relative illuminating powers are ed from what has been previously said.

this kind of determination great accuracy cannot be attained, more ally when the lights to be compared are of different colours, one, for ce, being yellow, and the other of a bluish tint. In this case, the nination of the relative brightness is quite uncertain.

eatstone's photometer.—The principal part of this instrument is a bead, P (fig. 352), fixed on the edge of a disc, which rotates on a , *o*, working in a larger toothed wheel. The wheel fits in a cylin- copper box, which is held in one hand, while the other works a

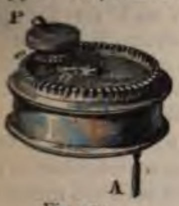


Fig. 352.

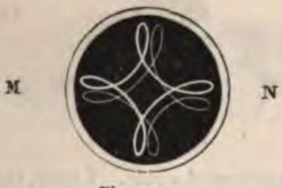


Fig. 353.

, A, which turns a central axis, the motion of which is transmitted poke, *a*, to the pinion *o*. In this way the latter turns on itself, and same time revolves round the circumference of the box; the bead shares this double motion, and consequently describes a curve form of a rose (fig. 353).

Now, let M and N be the two lights whose intensities are to b pared; the photometer is placed between them and rapidly rotated brilliant points produced by the reflection of the light on the two c sides of the bead give rise to two luminous bands, arranged as repr in fig. 353. If one of them is more brilliant than the other—that proceeds from the light M, for instance—the instrument is nearer the other light until the two bands exhibit the same brig The distance of the photometer from each of the two lights then measured, their intensities are proportional to the squares distances.

CHAPTER II.

REFLECTION OF LIGHT. MIRRORS.

474. **Laws of the reflection of light.**—When a luminous ray a polished surface, it is reflected according to the following tw which, as we have seen, also prevail for heat :—

I. *The angle of reflection is equal to the angle of incidence.*

II. *The incident and the r ray are both in the same which is perpendicular to th ting surface.*

The words are here used same sense as in article 37 need no further explanation.

First proof.—The two la be demonstrated by the ap represented in fig. 354. It c of a graduated circle in a plane. Two brass slides round the circumference; of them there is a piece of glass, P, and on the ot opaque screen, N, in the c which is a small aperture. to the latter slide there is mirror, M, which can be less inclined, but always re a plane perpendicular to t of the graduated circle. Lastly, there is a small polished metalli *m*, placed horizontally in the centre of the circle.

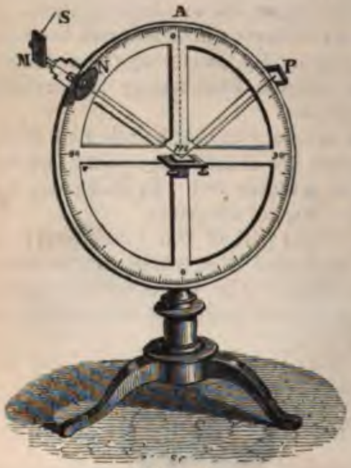


Fig. 354.

In making the experiment, a pencil of solar light, S, is c impinge on the mirror M, which is so inclined that the reflect passes through the aperture in N, and falls on the centre of the n luminous pencil then experiences a second reflection in a direction , which is ascertained by moving P until an image of the aperture is nd in its centre. The number of degrees comprised in the arc AN is n read off, and likewise that in AP ; these being equal, it follows that angle of reflection A*m*P is equal to the angle of incidence A*m*M.

The second law follows from the arrangement of the apparatus, the ne of the rays M*m* and *m*P being parallel to the plane of the graduated cle, and, consequently, perpendicular to the mirror *m*.

econd Proof.—The law of the reflection of light may also be demon- ated by the following experiment, which is susceptible of greater accu- y than that just described. In the centre of a graduated circle, M . 355), placed in a vertical position, there is a small telescope movable a plane parallel to the limb ; at a suitable distance there is a vessel full mercury, which forms a perfectly horizontal plane mirror. Some par- ular star of the first or second magnitude is viewed through the tele- pe in the direction AE, and the telescope is then inclined so as to receive e ray AD coming from the star after being reflected from the brilliant rface of the mercury. In this way the two angles formed by the rays A and DA, with the horizontal AH, are found to be equal, from which it

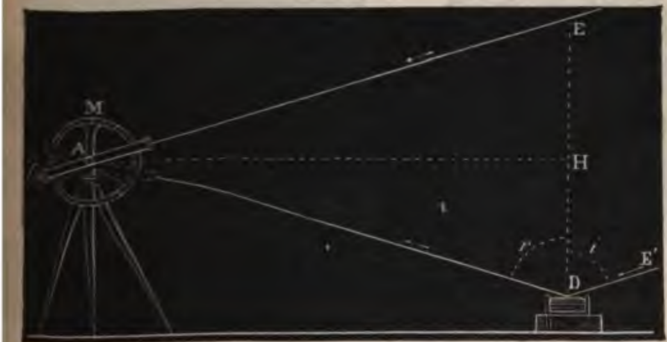


Fig. 355.

y easily be shown that the angle of incidence E′DE is equal to the le of reflection EDA. For if DE is the normal to the surface of the cury, it is perpendicular to AH, and AED, ADE are the conplements he equal angles EAH, DAH ; therefore AED, ADE are equal ; but two rays AE and DE′ may be considered parallel, in consequence of great distance of the star, and therefore the angles EDE′ and DEA qual, for they are alternate angles, and, consequently, the angle EDE′ ual to the angle EDA.

REFLECTION OF LIGHT FROM PLANE SURFACES.

. **Mirrors. Images.**—*Mirrors* are bodies with polished surfaces h show by reflection objects presented to them. The place at which objects appear is their *image.* According to their shape, mirrors into *plane, concave, convex, spherical, parabolic, conical,* etc.

476. **Formation of images by plane mirrors.**—The deter the position and size of images resolves itself into investigating of a series of points. And first, the case of a single point, A, fore a plane mirror, MN (fig. 356), will be considered. Any r cident from this point on the mirror, is reflected in the dir making the angle of reflection DBO equal to the angle of incid

If now a perpendicular, AN, be let fall from the point A on and if the ray OB be prolonged below the mirror until it mee pendicular on the point *a*, two triangles are formed, ABN which are equal, for they have the side BN common to bo angles ANB, ABN, equal to the angles *a*NB, *a*BN ; for the a and *a*NB are right angles, and the angles ABN and *a*BN are angle OBM. From the equality of these triangles, it follows equal to AN ; that is, that any ray, AB, takes such a direction reflected, that its prolongation below the mirror cuts the perpe in the point *a*, which is at the same distance from the mirror

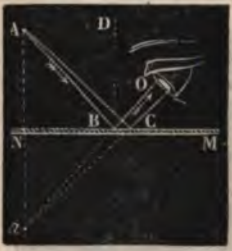


Fig. 356.

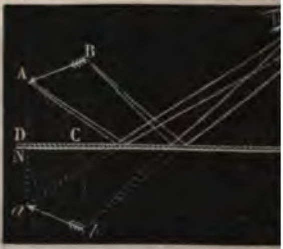


Fig. 357.

A. This applies also to the case of any other ray from the p for example. From this the important consequence follows, from the point A, reflected from the mirror, *follow, after reflect direction as if they had all proceeded from the point a.* Th ceived, and sees the point A at *a*, as if it were really situated in plane mirrors *the image of any point is formed behind the distance equal to that of the given point, and on the perpendic from this point on the mirror.*

It is manifest that the image of any object will be obtained b ing according to this rule the image of each of its points, or, those which are sufficient to determine its form. Fig. 357 sh image *ab* of any object, AB, is formed.

It follows from this construction that in plane mirrors *the the same size as the object,* for if the trapezium ABCD be ap trapezium DC*ab*, they are seen to coincide, and the object AB its image.

A further consequence from the above construction is, th image is symmetrical in reference to the object, and not in-

tual and real images.—There are two cases relative to the f rays reflected by mirrors according as the rays after reflection gent or divergent. In the first case the reflected rays do not f they are supposed to be produced on the other side of the ir prolongations coincide in the same point, as shown in figs. 7. The eye is then affected, just as if the rays proceeded from and it sees an image. But the image has no real existence, the ays do not come from the other side of the mirror; this appear-led the *virtual image*. The images of real objects produced by ors are of this kind.

second case, where the reflected rays converge, of which we have an example in concave mirrors, the rays coincide at a ont of the mirror, and on the same side as the object. They an image called the *real image*, for it can be received on a he distinction may be expressed by saying that *real images are ed by the reflected rays themselves, and virtual images those their prolongations.*

ltiple images formed by glass mirrors.—Metallic mirrors e but one reflecting surface only give one image; glass mirrors several images, which are readily observed when the image e is looked at obliquely in a looking-ery feeble image is first seen, and then inct one; behind this there are several hose intensities gradually decrease disappear.

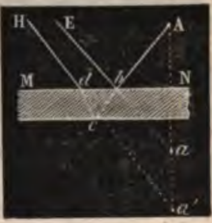


Fig. 358.

enomenon arises from the looking-ng two reflected surfaces. When the the point A meet the first surface, a lected and forms an image, *a*, of the on the prolongation of the ray *b*E, y this surface; the other part passes lass, and is reflected at *c*, from the layer of metal which covers surface of the glass, and reaching the eye in the direction *d*H, image *a′*. This image is distant from the first by double the of the glass. It is more intense, because metal reflects better

rd to the other images it will be remarked, that whenever light tted from one medium to another—for instance, from glass to air— of the rays get through, the remainder are reflected at the sur-bounds the two media. Consequently when the pencil *cd*, re-m *c*, attempts to leave the glass at *d*, most of the rays composing o the air, but some are reflected at *d*, and continue within the ese are again reflected by the metallic surface, and form a third ; after this reflection they come to MN, when many emerge the third image visible, but some are again reflected within the in a similar manner give rise to a fourth, fifth, etc. image, thereby completing the series above described. It is manifest above explanation that each image must be much feebler tha preceding it, and consequently not more than a small number a —ordinarily not more than eight or ten in all.

This multiplicity of images is objectionable in observations, an ingly, metallic mirrors are preferable in optical instruments.

479. **Multiple images from two plane mirrors.**—When a is placed between two plane mirrors, which form an angle v other, either right or acute, images of the object are formed, th of which increases with the inclination of the mirrors. If th right angles to each other, three images are seen, arranged sented in fig. 359. The rays OC and OD from the point O, afte reflection, give the one an image O′, and the other an image O″, ray OA, which has undergone two reflections at A and B, gives image, O‴. When the angle of the mirrors is 60°, five image duced, and seven if it is 45°. The number of images contin crease in proportion as the angle diminishes, and when it is zero when the mirrors are parallel—th of images is theoretically infinit multiplicity arises from the fact luminous rays undergo an increas ber of reflections from one mir other.

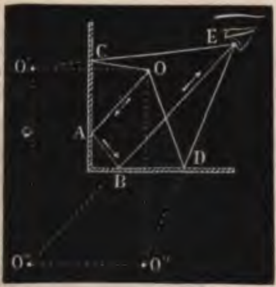


Fig. 359.

The *kaleidoscope*, invented b Brewster, depends on this prope clined mirrors. It consists of a which are three mirrors incline one end of the tube is closed by a ground glass, and the other by a vided with an aperture. Small pieces of coloured glass are plac end between the ground glass and another glass disc, and or through the aperture, the other end being held towards the ligh jects and their images are seen arranged in beautiful symmetric by turning the tube an endless variety of these shapes is obtain

480. **Irregular reflection.**—The reflection from the surfaces of bodies, the laws of which have just been stated, is called the *r specular reflection*; but the quantity thus reflected is less than the light. The light incident on an opaque body actually separates i parts: one is reflected regularly, another *irregularly*, that is, in tions; while a third is extinguished, or absorbed by the reflect If light falls on a transparent body, a considerable portion is tra with regularity.

The irregularly reflected light is called *scattered light*: it is th makes bodies visible. The light which is reflected regularly does us the image of the reflecting surface, but that of the body from w light proceeds. If, for example, a solar beam be incident on a well mirror in a dark room, the more perfectly the light is reflecte sible is the mirror in the different parts of the room. The eye does not erceive the image of the mirror, but that of the sun. If the reflecting ower of the mirror be diminished by sprinkling on it a light powder, the olar image becomes feebler, and the mirror is visible from all parts of the oom. Perfectly smooth, polished reflecting surfaces, if such there were, ould be invisible.

481. **Intensity of reflected light.** — The intensity of the reflecting ower of a body increases with the degree of polish and with the bliquity of the incident ray. For instance, if a sheet of white paper be placed before a candle, and be looked at very obliquely, an image of the lame is seen by reflection, which is not the case if the eye receives less blique rays.

The intensity of the reflection varies with different bodies, even when he degree of polish and the angle of incidence are the same. It also aries with the nature of the medium which the ray is traversing before and after reflection. Polished glass immersed in water loses a great part of its reflecting power.

REFLECTION OF LIGHT FROM CURVED SURFACES.

482. **Spherical mirrors.**—It has been already stated (475) that there re several kinds of curved mirrors; those most frequently employed are pherical and parabolic mirrors.

Spherical mirrors are those whose curvature is that of a sphere; their urface may be supposed to be formed by the revolution of an arc, MN fig. 360), about the radius CA, which unites the middle of the arc to the entre of the circle of which it is a part. According as the reflection takes lace from the internal or the external face of the mirror it is said to be *oncave* or *convex*. C, the centre of the hollow sphere, of which the mirror orms part, is called the *centre of curvature* or *geometrical centre*: the oint A is the centre of the figure. The infinite right line, AL, which asses through A and C, is the *principal axis* of the mirror: any right ne which simply passes through the centre C, and not through the point , is a *secondary* axis. The angle MCN, formed by joining the centre nd extremities of the mirror, is the *aperture*. A *principal* or *meridional ection* is any section made by a plane through its principal axis. In peaking of mirrors those lines alone will be considered which lie in the ame principal section.

The theory of the reflection of light from curved mirrors is easily educed from the laws of reflection from plane mirrors, by considering e surface of the former as made up of an infinitude of extremely small lane surfaces, which are its *elements*. The normal to the curved surface t a given point is the perpendicular to the corresponding element, or, hat is the same thing, to its corresponding tangent plane. It is shown geometry that in spheres all the normals pass through the centre of urvature, so that the normal may readily be drawn to any point of a herical mirror.

483. **Focus of a spherical concave mirror.**—In a curved mirror the *cus* is a point in which the reflected rays meet or tend to meet if pro-

duced either backwards or forwards; there may either be a *real focus* or a *virtual focus*.

Real focus.—We shall first consider the case in which the luminous rays are parallel to the principal axis, which presupposes that the luminous body is at an infinite distance; let GD (fig. 360) be such a ray.

From the hypothesis that curved mirrors are composed of a number of infinitely small plane elements, this ray would be reflected from the element corresponding to the point D, according to the laws of the reflection from plane mirrors (474); that is, that CD being the normal at the point of incidence D, the angle of reflection CDF is equal at the angle of incidence GDC, and is in the same plane. It follows from this that the point F, where the reflected ray cuts the principal axis, divides the radius of curvature AC very nearly into two equal parts. For in the triangle DFC, the angle DCF is equal to the angle CDG, for they are alternate and opposite angles; likewise the angle CDF is equal to the angle CDG, from the laws of reflection; therefore the angle FDC is equal to the angle FCD, and the sides FC and FD are equal as being opposite to equal angles. Now the smaller the arc, AD, the more nearly does DF equal AF; and when the arc is only a small number of degrees, the right lines AF and FC may be taken as approximately equal, and the point F may be taken as the middle of AC. So long as the aperture of the mirror does not exceed 8 to 10 degrees, any other ray, HB, will after reflection pass very nearly through the point F. Hence, when a pencil of rays parallel to the axis falls on a concave mirror, the rays intersect after reflection in the same point, which is at an equal distance from the centre of curvature and from the mirror. This point is called the *principal focus* of the mirror, and the distance AF is the *principal focal distance*.

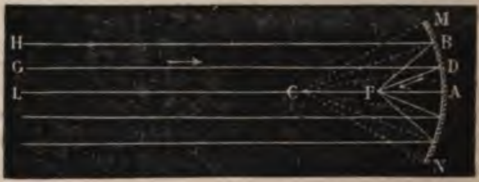


Fig. 360.

All rays parallel to the axis meet in the point F; and, conversely, if a luminous object be placed at F, the rays emitted by this object will after reflection take the directions DG, BH, parallel to the principal axis; for in this case the angles of incidence and reflection have changed places; but these angles always remain equal.

The case is now to be considered in which the rays are emitted from a luminous point, L (fig. 361), placed on the principal axis, but at such a distance that they are not parallel, but divergent. The angle LKC, which the incident ray LK forms with the normal KC, is smaller than the angle SKC, which the ray SK parallel to the axis forms with the same normal, and, consequently, the angle of reflection corresponding to the ray LK ust be smaller than the angle CKF, corresponding to the ray SK. And, erefore, the ray LK will meet the axis after reflection at a point, *l*, be- een the centre C and the principal focus F. So long as the aperture the mirror does not exceed a small number of degrees, all the rays om the point L will intersect after reflection in the point *l*. This point called the *conjugate focus*, in order to indicate the connection between e points L and *l*. These points are reciprocal to each other, that is, if e luminous point were transferred to *l*, its conjugate focus would be at *l*K being the incident and KL the reflected ray.

On considering the figure 361 it will be seen that when the object L is ought near to or removed from the centre C, its conjugate focus ap- oaches or recedes in a corresponding manner, for the angles of inci- nce and reflection increase or decrease together.

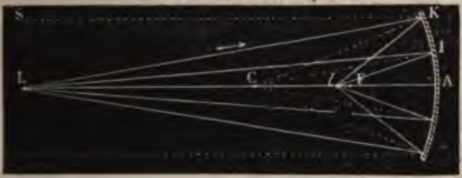


Fig. 361.

If the object L coincide with the centre C, the angle of incidence is ll, and as the angle of reflection must be the same, the ray is reflected itself, and the focus coincides with the object. When the luminous ject is between the centre C and the principal focus, the conjugate cus in turn is on the other side of the centre, and is further from the ntre according as the luminous point is nearer the principal focus. If e luminous point coincides with the principal focus, the reflected rays, ing parallel to the axis, will not meet, and there is, consequently, no cus.

Virtual focus.—There is, lastly, the case in which the object is placed L, between the principal focus and the mirror (fig. 362). Any ray, M, emitted from the point L, makes with the normal CM an angle of cidence, LMC, greater than FMC; the angle of reflection must be eater than CMS, and therefore the reflected ray ME diverges from the s AK. This is also the case with all rays from the point L, and hence

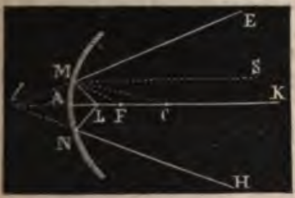


Fig. 362.

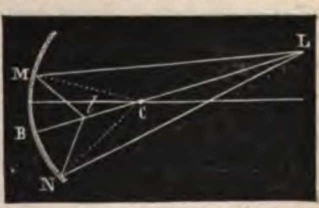


Fig. 363.

these rays do not intersect, and, consequently, form no conjugate fo but if they are conceived to be prolonged on the other side of the mi their prolongations will intersect in the same point, *l*, on the axis, and eye experiences the same impression as if the rays were emitted from point *l*. Hence a *virtual focus* is formed quite analogous to those for by plane mirrors (477).

In all these cases it is seen that the position of the principal focu constant, while that of the conjugate foci and of the virtual foci v *The principal and the conjugate foci are always on the same side o mirror as the object*, while *the virtual focus is always on the other si the mirror.*

Hitherto the luminous point has always been supposed to be place the principal axis itself, and then the focus is formed on this axis. the case in which the luminous point is situate on a secondary axis, (fig. 363), by applying to this axis the same reasoning as in the prece case, it will be seen that the focus of the point L is formed at a poi on the secondary axis, and that, according to the distance of the poin the focus may be either principal, conjugate, or virtual.

484. **Foci of convex mirrors.**—In convex mirrors there are only vi foci. Let SI, TK . . . (fig. 364) be rays parallel to the principal ax a convex mirror. These rays, after reflection, take the diverging d tions IM, KH, which, when continued, meet in a point, F, which is

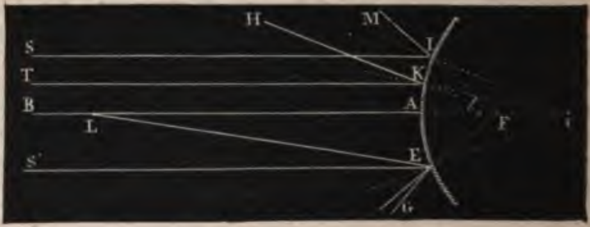


Fig. 364.

principal virtual focus of the mirror. By means of the triangle CK may be shown, in the same manner as with concave mirrors, that point F is approximately the middle of the radius of curvature, CA.

If the incident luminous rays, instead of being parallel to the proceed from a point, L, situated on the axis at a finite distance, it once seen that a virtual focus will be formed between the principal f F and the mirror.

485. **Determination of the principal focus.**—In the application concave and convex mirrors, it is often necessary to know the radi curvature. This is tantamount to finding the principal focus; for b situated at the middle of the radius, it is simply necessary to double focal distance.

To find this focus with a concave mirror, it is exposed to the sun's so that its principal axis is parallel to them, and then with a small sc nd glass the point is sought at which the image is formed with the st intensity : this is the principal focus. The radius of the mirror is e this distance.

the mirror is convex it is covered with paper, but two small portions, nd I, are left exposed at equal distances from the centre of the figure nd on the same principal section (fig. 365). A screen, MN, in the tre of which is an opening larger than the distance HI, is placed ore the mirror. If a pencil of solar rays, SH, S′I, parallel to the axis, on the mirror, the light is reflected at H and I, on the parts where the rror is left exposed, and forms on the screen two brilliant images at *h* d *i*. By moving the screen MN nearer to or farther from the mirror, a

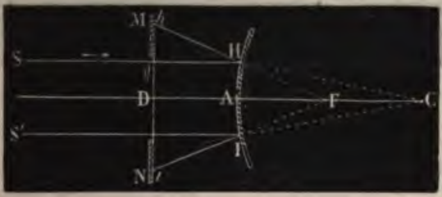


Fig. 365.

on is found at which the distance *hi* is double that of HI. The dis- AD from the screen to the mirror then equals the principal focal ice. For the arc HAI does not sensibly differ from its chord, and se the triangles FHI and F*hi* are similar, $\frac{HI}{hi}=\frac{FA}{FD}$; but HI is half and therefore also FA is the half of FD, and therefore AD is equal . Further, FA is the principal focal distance ; for the rays SH and e parallel to the axis : consequently also twice the distance AD s the radius of curvature of the mirror.

. **Formation of images in concave mirrors.**—Hitherto it has been sed that the luminous or illuminated object placed in front of the r was simply a point ; but if this object has a certain magnitude, we onceive a secondary axis drawn through each of its points, and series of real or virtual foci could be determined, the collection of composes the image of the object. By the aid of the construc- which have served for determining the foci, we shall investigate sition and magnitude of these images in concave and in convex rs.

l image.—We shall first take the case in which the mirror is con- and the object AB (fig. 366) is on the other side of the centre. To the image or the focus of any point, A, a secondary axis, AE, is from this point, and then drawing from the point A an incident D, the normal to this point, CD, is taken, and the angle of reflec- D*a* is made equal to the angle of incidence ADC. The point *a*, the reflected ray cuts the secondary axis AE, is the conjugate focus point A, because every other ray drawn from this point passes h with *a*. Similarly if a secondary axis, BI, be drawn from the

point B, the rays from this point meet after reflection in *b*, and form
conjugate focus of B. And as the images of all the points of the obj
are formed between *a* and *b*, *ab* is the complete image of AB. Fr
what has been said about foci (483), it appears that *this image is r*
inverted, smaller than the object, and placed between the centre of curvat
and the principal focus. This image may be seen in two ways ; by plac

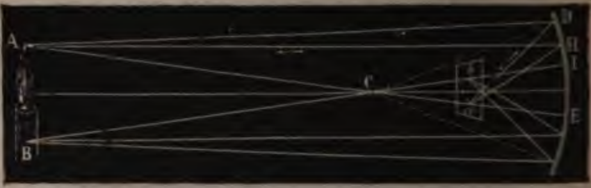


Fig. 366.

the eye in the continuation of the reflected rays, and then it is an a
image which is seen ; or the rays are collected on a screen, on which
image appears to be depicted.

If the luminous or illuminated object is placed at *ab*, between
principal focus and the centre, its image is formed at AB. It is th
real but inverted image ; it is greater than the object, *and the greate*
the object, ab, is nearer the focus.

If the object is placed in the principal focus itself, no image is
duced ; for then the rays emitted from each point form, after reflect
as many pencils respectively parallel to the secondary axis, whic

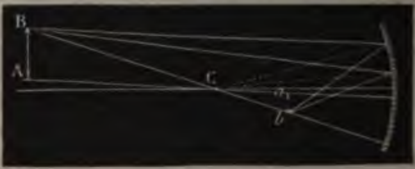


Fig. 367.

drawn through the point from which they are emitted (483), and h
neither foci nor images are formed.

When all points of the object AB are above the principal axis (fig.
by repeating the preceding construction, it is readily seen that the i
of the object is formed at *ab*.

Virtual image.—The case remains in which the object is placed
tween the principal focus and the mirror. Let AB be this object
368) ; the incident rays after reflection take the directions DI and
and their prolongations form a virtual image, *a*, of the point A, on
secondary axis. Similarly, an image of B is formed at *b*, conseque
the eye sees at *ab* the image of AB. *This image is virtual, erect,*
larger than the object.

m what has been stated, it is seen that according to the distance of ject concave mirrors produce two kinds of images, or none at all; on notices this by placing himself before a concave mirror. At a

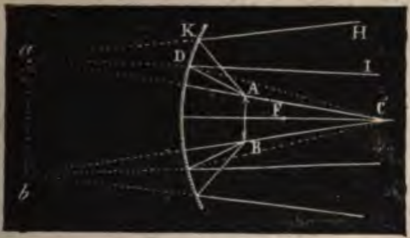


Fig. 368.

n distance he sees an image of himself inverted and smaller: this real image: at a less distance the image becomes confused, and pears when he is at the focus; still nearer the image appears erect, rger—it is then a virtual image.

. **Formation of images in convex mirrors.**—Let AB (fig. 369) object placed before a mirror at any given distance. AC and BC econdary axes, and it follows from what has been already stated, ll the rays from A are divergent after reflection, and that their

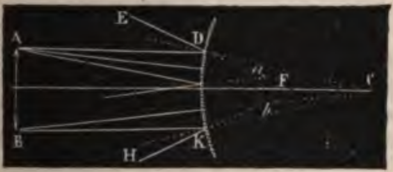


Fig. 369.

gations pass through a point, *a*, which is the virtual image of the A. Similarly the rays from B form a virtual image of it in the *b*. The eye which receives the divergent rays DE, KA, . . . sees in image of AB. Hence, whatever the position of an object before a x mirror, *the image is always virtual, erect, and smaller than the*

. **Formulæ for spherical mirrors.**—The relation between the on of an object and that of its image in spherical mirrors may be

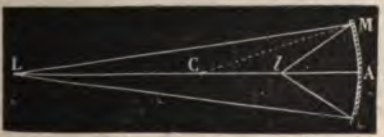


Fig. 370.

sed by a very simple formula. In the case of concave mirrors, let its radius of curvature, *p* the distance LA of the object, L (fig. 370), and p' the distance lA of the image from the mirror. In the triangle LMl, the normal MC divides the angle LMl in two equal parts, and from geometry it follows that the two segments LC, Cl are to each other as the two sides containing the angle; that is, $\frac{Cl}{CL} = \frac{lM}{LM}$: therefore $Cl \times LM = CL \times lM$.

If the arc AM does not exceed 5 or 6 degrees, the lines ML and Ml are approximately equal to AL and Al; that is, to p and p'.

Further, $$Cl = CA - Al = R - p',$$

and also $$CL = AL - AC = p - R.$$

These values substituted in the preceding equations give

$$(R - p')\,p = (p - R)\,p',$$
$$Rp - pp' = pp' - Rp'.$$

From which transposing and reducing we have

$$Rp + Rp' = 2pp' \quad . \quad . \quad . \quad . \quad (1)$$

If the terms of this equation be all divided by $pp'R$, we obtain

$$\frac{1}{p'} + \frac{1}{p} = \frac{2}{R} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

which is the usual form of the equation.

From the equation (1) we get

$$p' = \frac{pR}{2p - R} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which gives the distance of the image from the mirror, in terms of the distance of the object, and of the radius of curvature.

489. **Discussion of the formulæ for mirrors.**—We shall now investigate the different values of p', according to the values of p in the formula (3).

i. Let the object be placed at an infinite distance on the axis, in which case the incident rays are parallel. To obtain the value of p', both terms of the fraction (3) must be divided by p, which gives

$$p' = \frac{R}{2 - \frac{R}{p}} \quad . \quad . \quad . \quad . \quad (4)$$

as p is infinite, $\frac{R}{p}$ is zero, and we have $p' = \frac{R}{2}$; that is, the image is formed in the principal focus, as ought to be the case, for the incident rays are parallel to the axis.

ii. If the object approaches nearer the mirror, p decreases, and as the denominator of the formula (4) diminishes, the value of p' increases; consequently the image approaches the centre at the same time as the object, but it is always between the principal focus and the centre, for so long as

$$p \text{ is } > R, \text{ we have } \frac{R}{2 - \frac{R}{p}} > \frac{R}{2} \text{ and } < R.$$

hen the object coincides with the centre, $p = R$, and, consequently,
that is, the image coincides with the object.

hen the luminous object is between the centre and the principal
$< R$, and hence from the formula (4), $p' > R$; that is, the image is
n the other side of the centre. When the object is in the focus,
hich gives $p' = \frac{R}{0} = \infty$; that is, the image is at an infinite dis-
r the reflected rays are parallel to the axis.

tly, if the object is between the principal focus and the mirror,
$< \frac{R}{2}$; p' is then negative, because the denominator of the for-
is negative. Therefore, the distance p' of the mirror from the
ust be calculated on the axis in a direction opposite to p. The
then virtual, and is on the other side of the mirror.

g p' negative in the formula (2), it becomes $\frac{1}{p} - \frac{1}{p'} = \frac{2}{R}$; in this
omprehends all cases of virtual images in concave mirrors.

case of convex mirrors, the image is always virtual (487) ; p' and
the same sign, since the image and the centre are on the same
he mirror, while the object being on the opposite side, p is of the
sign ; hence in the formula (2) we get

$$\frac{1}{p'} - \frac{1}{p} = \frac{2}{R} \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

rmula for convex mirrors. It may also be found directly by the
ometrical considerations as those which have led to the formula
oncave mirrors.

st be observed that the preceding formulæ are not rigorously true,
h as they depend upon the hypothesis that the lines LM and *l*M
) are equal to LA and A*l*; although this is not true, the error
hes without limit with the angle MCA : and when this angle does
ed a few degrees, the error is so small that it may, in practice, be
ed.

Calculation of the magnitude of images.—By means of the
formulæ the magnitude of an image may be calculated, when the

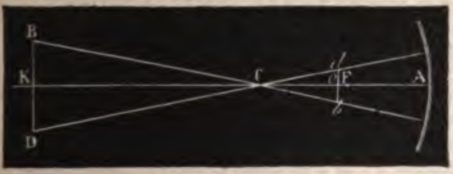


Fig. 371.

e of the object, its magnitude, and the radius of the mirror are
For if BD be the object (fig. 371), *bd* its image, and if the distance

KA and the radius AC be known, A*o* can be calculated by means of formula (3) of article 488. A*o* known, *o*C can be calculated. But as the triangles BCD and *d*C*b* are similar, their bases and heights are in the proportion *bd* : BD = C*o* : CK, or

Length of the image : length of the object
= distance from image to centre : distance from the object to centre.

491. **Spherical aberration. Caustics.**—In the foregoing theory of the foci and images of spherical mirrors, it has already been observed that the reflected rays only pass through a single point when the aperture of the mirror does not exceed 8 or 10 degrees (483). With a larger aperture, the rays reflected near the edges meet the axis nearer the mirror than those that are reflected at a small distance from the neighbourhood of the centre of the mirror. Hence arises a want of precision in these images, which is called *spherical aberration* by reflection, to distinguish it from the spherical aberration by refraction, which occurs in the case of lenses.

Every reflected ray cuts the one next to it (fig. 372), and their points of intersection form in space a curved surface, which is called the *caustic by reflection.* The curve FM represents one of the branches of a section of this surface made by the plane of the paper. When the light of a candle is reflected from the inside of a cup or tumbler, a section of the caustic surface can be seen by partly filling the cup or tumbler with milk.

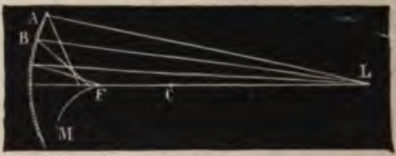


Fig. 372.

492. **Applications of mirrors.**—The applications of plane mirrors in domestic economy are well known. Mirrors are also frequently used in physical apparatus for sending light in a certain direction. The solar light can only be sent in a constant direction by making the mirror moveable. It must have a motion which compensates for the continual change in the direction of the sun's rays produced by the apparent diurnal motion of the sun. This result is obtained by means of a clockwork motion, to which the mirror is fixed, and which causes it to follow the course of the sun. This apparatus is called the *heliostat*. The reflection of light is also used to measure the angles of crystals by means of the instruments known as *reflecting goniometers.*

Concave spherical mirrors are also often used. They are applied for magnifying *mirrors*, as in a shaving mirror. They have been employed for burning mirrors, and are still used in telescopes. They also serve as reflectors, for conveying light to great distances, by placing a luminous object in their principal focus. For this purpose, however, parabolic mirrors are preferable.

Parabolic mirrors.—*Parabolic mirrors* are concave mirrors, surface is generated by the revolution of the arc of a parabola, AM, ts axis, AX (fig. 373).

s been already stated that in spherical mirrors the rays parallel to s converge only approximately to the principal focus, and reciprocally source of light is placed in ncipal focus of these mirrors, lected rays are not exactly l to the axis. Parabolic are free from this defect; e more difficult to construct, far better for reflectors. It ll-known property of a paraat the right line FM, drawn e focus F, to any point, M, urve, and the line ML, pao the axis AF, make equal with the tangent TT′ at this Consequently, all rays parallel to the axis after reflection meet in cus of the mirror F, and, conversely, when a source of light is in the focus, the rays incident on the are reflected exactly parallel to the The light thus reflected tends to main intensity even at a great distance, for been seen (472) that it is the diverf the luminous rays which principally s the intensity of light.

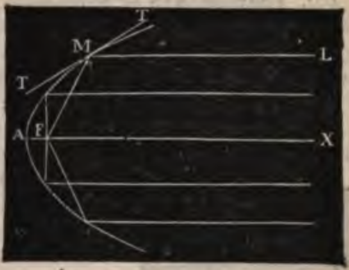


Fig. 373.

from this property that parabolic are used in carriage lamps, and in nps placed in front of and behind trains. These reflectors were forused for lighthouses, but have been d by lenticular glasses.

n two equal parabolic mirrors are cut ane perpendicular to the axis passing the focus, and are then united at tersections, as shown in the figure that their foci coincide, a system of rs is obtained with which a single lamp illuminates in two direconce. This arrangement is used in lighting staircases.

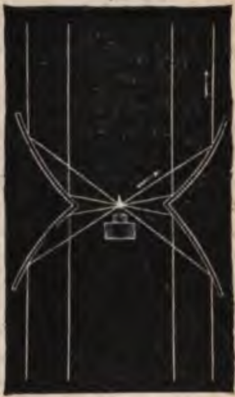


Fig. 374.

CHAPTER III.

SINGLE REFRACTION. LENSES.

494. **Phenomenon of refraction.**—*Refraction* is the deflectic luminous rays experience in passing obliquely from one me another; for instance, from air into water. We say obliquely, b the incident ray is perpendicular to the surface separating the tw it is not deflected, and continues its course in a right line.

The *incident ray* being represented by SO (fig. 375), the *refr* is the direction OH which light takes in the second medium ; a angles SOA and HOB, which these r with the line AB, at right angles to th which separates the two media, the fi *angle of incidence*, and the other the *refraction*. According as the refracte proaches or deviates from the normal, th medium is said to be more or less *refr* *refracting* than the first.

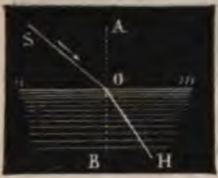


Fig. 375.

All the light which falls on a refractin does not completely pass into it ; one part is reflected and scatte another penetrates into the medium..

Analysis shows that the direction of refraction depends on th velocity of light in the two media. On the undulatory theory highly refracting medium is that in which the velocity of propa least.

In uncrystallised media, such as air, liquids, ordinary glass, the ray is singly refracted ; but in certain crystallised bodies, such a spar, selenite, etc., the incident ray gives rise to two refracted ra latter phenomenon is called *double refraction*, and will be dis another part of the book. We shall here deal exclusively wi *refraction.*

495. **Laws of single refraction.**—When a luminous ray is re passing from one medium into another of a different refractive p following laws prevail :—

I. *Whatever the obliquity of the incident ray, the ratio which of the incident angle bears to the sine of the angle of refraction i for the same two media, but varies with different media.*

II. *The incident and the refracted ray are in the same plane perpendicular to the surface separating the two media.*

These are known as *Descartes' laws*, and are demonstrate same apparatus as that used for the laws of reflection (450). T mirror in the centre of the graduated circle is replaced by a se drical glass vessel, filled with water to such a height that it exactly the height of the centre (fig. 376). If the mirror, M, be inclined that a reflected ray, MO, is directed towards the cen refracted on passing into the water, but it passes out without re hen its direction is at right angles to the curved sides of the n order to observe the course of the refracted ray, it is re- a screen, P, which is til the image of the aper- e screen N is formed in . In all positions of the and P, the sines of the incidence and refraction ured by means of two rules, movable so as to s horizontal, and hence ular to the diameter AD. ding off the lengths of the e angles MOA and DOP les I and R, the numbers to vary with the position reens, but their ratio is that is, if the sine of becomes twice or three large, the sine of refrac- eases in the same ratio, monstrates the first law.

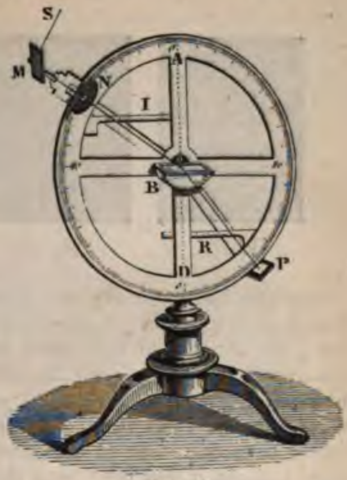


Fig. 376.

d law follows from the arrangement of the apparatus, for the he graduated limb is perpendicular to the surface of the liquid i-cylindrical vessel.

dex of refraction.—The ratio between the sines of the in- d refracted angle is called *index of refraction* or *refractive index*. with the media; for example, from air to water it is $\frac{4}{3}$, and from ss it is $\frac{3}{2}$.

edia are considered in an inverse order—that is, if light passes r to air, or from glass to air—it follows the same course, but in y direction, PO becoming the incident and OM the refracted sequently, the index of refraction is reversed; from water to en $\frac{3}{4}$, and from glass to air $\frac{2}{3}$.

fects produced by refraction.—In consequence of refraction, mersed in a medium more highly refracting than air appear surface of this medium, but they appear to be more distant if in a less refracting medium. Let L (fig. 377) be an object im- a mass of water. In passing thence into air, the rays LA, LB rge from the normal to the point of incidence, and assume the AC, BD . . . , the prolongations of which intersect approximately oint L′, placed on the perpendicular L′K. The eye receiving s sees the object L at L′. The greater the obliquity of the rays . . . the higher the object appears.

r the same reason that a stick plunged obliquely into water ent (fig. 378), the immersed part appearing raised.

to an effect of refraction, stars are visible to us even when they the horizon. For as the layers of the atmosphere are denser in proportion as they are nearer the earth, and as the refractive power of a gas increases with its density (508), it follows that on entering the

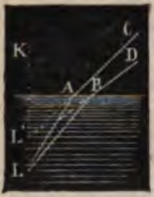


Fig. 377.

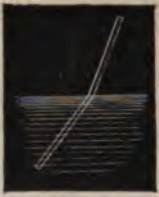


Fig. 378.

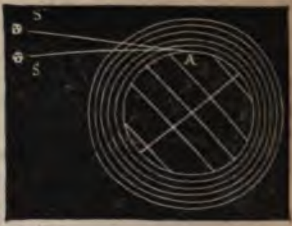


Fig. 379.

atmosphere the luminous rays become bent, as seen in the fig. 379, describing a curve before reaching the eye, so that we see the star at S' along the tangent of this curve instead of at S. In our climate the atmospheric refraction does not raise the stars when on the horizon more than half a degree.

498. **Total reflection. Critical angle.** — When a luminous ray passes from one medium into another which is less refracting, as from water into air, it has been seen that the angle of incidence is less than the angle of refraction. Hence, when light is propagated in a mass of water from S to O (fig. 380), there is always a value of the angle of incidence SOB, such that the angle of refraction, AOR, is a right angle, in which case the refracted ray emerges parallel to the surface of the water.

This angle, SOB, is called the *critical angle*, since for any greater angle, POB, the incident ray cannot emerge, but undergoes an internal reflection, which is called *total reflection*, because the incident light is entirely reflected. From water to air the critical angle is 48° 35′; from glass to air, 41° 48′.

The occurrence of this internal reflection may be observed by the following experiment. An object, A, is placed before a glass vessel filled with water (fig. 381); the surface of the liquid is then looked at as

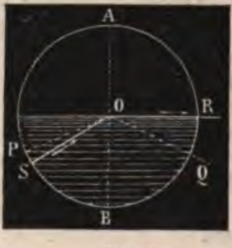


Fig. 380.

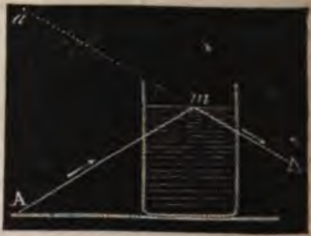


Fig. 381.

shown in the figure, and an image of the object A is seen at *a*, formed by the rays reflected at *m*, in the ordinary manner of a mirror.

nilar effects of the total reflection of the images of objects contained uaria are frequently observed, and add much to the interest of their arance.

). **Mirage.**—The *mirage* is an optical illusion by which inverted es of distant objects are seen as if below the ground or in the sphere. This phenomenon is of most frequent occurrence in hot tes, and more especially on the sandy plains of Egypt. The ground

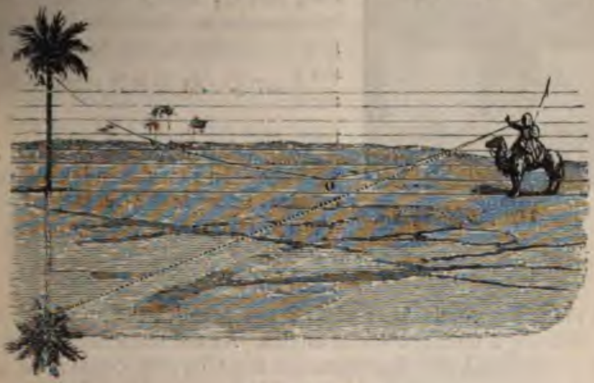


Fig. 382.

has often the aspect of a tranquil lake, on which are reflected trees the surrounding villages. The phenomenon has long been known, Monge, who accompanied Napoleon's expedition to Egypt, was the to give an explanation of it.

is a phenomenon of refraction, which results from the unequal ity of the different layers of the air when they are expanded by act with the heated soil. The least dense layers are then the lowest, a luminous ray from an elevated object, A (fig. 382), traverses layers h are gradually less refracting; for, as will be shown presently , the refracting power of a gas diminishes with lessened density. angle of incidence accordingly increases from one layer to the other, ultimately reaches the critical angle, beyond which internal reflec- succeeds to refraction (498). The ray then rises, as seen in the e, and undergoes a series of successive refractions, but in a direction rary to the first, for it now passes through layers which are gradually refracting. The luminous ray then reaches the eye with the same ction as if it had proceeded from a point below the ground, and hence ves an inverted image of the object, just as if it had been reflected at point O, from the surface of a tranquil lake.

ariners sometimes see images in the air of the shores or of distant els. This is due to the same cause as the mirage, but in a contrary ction, only occurring when the temperature of the air is above that ie sea, for then the inferior layers of the atmosphere are denser, owing ieir contact with the surface of the water.

TRANSMISSION OF LIGHT THROUGH TRANSPARENT MEDIA.

500. **Media with parallel faces.**—When light traverses a me with parallel faces the *emergent* rays are parallel to the incident rays

Let MN (fig. 383) be a glass plate with parallel faces, let SA b incident and DB the emergent ray, i and r the angles of incidence of refraction at the entrance of the and, lastly, i' and r' the same angl its emergence. At A the light unde a first refraction, the index of whi $\frac{\sin i}{\sin r}$ (476). At D it is refracted a se time, and the index is then $\frac{\sin i'}{\sin r'}$. we have seen that the index of refra of glass to air is the reciprocal of fraction from air to glass; hence

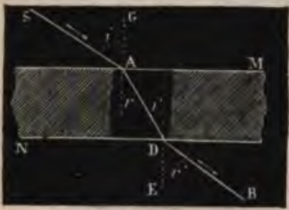


Fig. 383.

$$\frac{\sin i'}{\sin r'} = \frac{\sin r}{\sin i}.$$

But as the two normals AG and DE are parallel, the angles r and equal, as being alternate interior angles. As the numerators in the equation are equal, the denominators must be also equal; the ang and i are therefore equal, and hence DB is parallel to SA.

501. **Prism.**—In optics a *prism* is any transparent medium comp between two plane faces inclined to each other. The intersecti these two faces is the *edge* of the prism, and their inclination refracting angle. Every section perpendicular to the edge is cal *principal section.*

The prisms used for experiments are generally right triangular p of glass, as shown in the fig. 384, and their principal section is a tri (fig. 385). In this section the point A is called the *summit* of the p and the right line BC is called the *base*; these expressions have refe to the triangle ABC, and not to the prism.

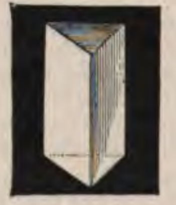


Fig. 384.

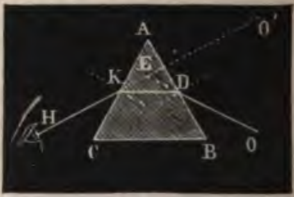


Fig. 385.

502. **Path of rays in prisms. Angle of deviation.**—When the of refraction are known, the passage of rays in a prism is readily d mined. Let O be a luminous point (fig. 385) in the same plane as principal section ABC of a prism, and let OD be an incident ray. ray is refracted at D, and approaches the normal, because it passes a more highly refracting medium. At K it experiences a second r

on, but it then deviates from the normal, for it passes into air, which is
ss refractive than glass. The light is thus refracted twice in the same
rection, so that *the ray is deflected towards the base,* and consequently
e eye which receives the emergent ray KH sees the object O at O′;
at is, *objects seen through a prism appear deflected towards its summit.*
he angle OEO′, which the incident and emergent rays form with each
her, expresses the deviation of light caused by the prism, and is called
e angle of deviation.

Besides this, objects seen through a prism appear in all the colours
the rainbow; this phenomenon will be described under the name of
spersion.

This angle increases with the refractive index of the material of the
ism, and also with its refracting angle. It also varies with the angle

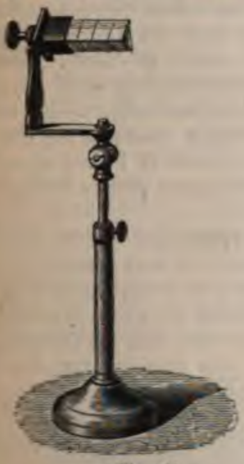


Fig. 386.

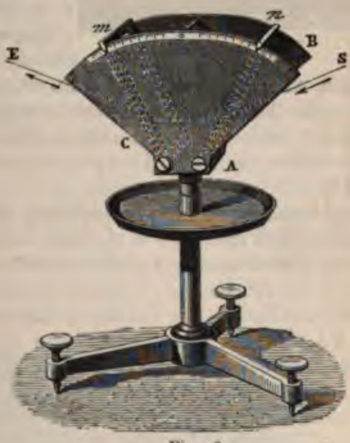


Fig. 387.

nder which the luminous ray enters the prism. The angle of deviation
ncreases up to a certain limit, which is determined by calculation, know-
ng the angles of incidence of the ray, and the refracting angle of the
rism.

That the angle of deviation increases with the refractive index may be
hown by means of the *polyprism.* This name is given to a prism
ormed of several prisms of the same angle connected at their bases
ig. 386). These prisms are made of substances unequally refringent,
uch as flint glass, rock crystal, or crown glass. If any object—a line,
or instance—be looked at through the polyprism, its different parts are
een at unequal heights. The highest portion is that seen through the
int glass, the refractive index of which is greatest; then the rock
rystal; and so on in the order of the decreasing refractive indices.

The *prism with variable angle* is used for showing that the angle of
eviation increases with the refracting angle of the prism. It consists
two parallel brass plates, BC and C, fixed on a support. Between these

are two glass plates moving, on a hinge, with some friction agai plates, so as to close it. When water is poured into the ves angle may be varied at will. If a ray of light, S, be allowed to fa one of them, by inclining the other more, the angle of the pr creases, and the deviation of the ray is seen to increase.

503. **Application of right-angled prisms in reflectors.**— whose principal section is an isosceles right-angled triangle af important application of total reflection (498). For let ABC (fi be the principal section of such a O a luminous point, and OH a right angles to the face BC. T enters the glass without being re and makes with the face AB an equal to B, that is to 45 degrees, an fore greater than the limiting a glass, which is 41° 48′ (498). OH undergoes therefore at H to flection, which imparts to it a direction HI perpendicular to the face AC. Thus the hypothenuse surface of this produces the e the most perfect plane mirror, and an eye placed at I sees at image of the point O. This property of right-angled prisms is fre used in optical instruments.

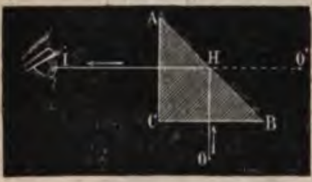


Fig. 388.

504. **Conditions of emergence in prisms.**—In order th luminous rays refracted at the first face of a prism may emerge fr second, it is necessary that the refractive angle of the prism be le twice the critical angle of the substance of which the prism is con For if LI (fig. 389) be the ray incident on the first face, IE the re ray, PI and PE the normals, the ray IE can only emerge fr second face when the incident angle IEP is less than the critica (498). But as the incident angle LIN increases, the angle EI increases, while IEP diminishes. Hence, according as the direc the ray LI tends to become parallel with the face AB, does this r to emerge at the second face.

Let LI be now parallel to AB, the angle r is then equal to the angle l of the prism, because it has its maximum value. F the angle EPK, the exterior of the triangle IPE, is eq $r+i'$; but the angles EPK are equal, because their sid perpendicular, and therefore $+i'$; therefore also $A=l+i'$ this case $r=l$. Hence, if or is $>2l$, we shall have i $>l$, and therefore the ray not emerge at the second fa would undergo internal refl and would emerge at a thir BC. This would be much the case with rays whose incident angle is less than BIN, beca

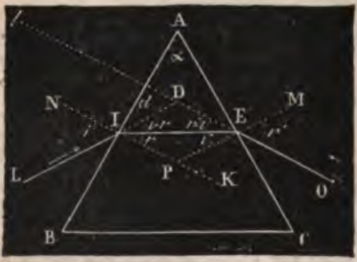


Fig. 389.

lready seen that i' continually increases. Thus, in the case in the refracting angle of a prism is equal to $2l$ or is greater, no us ray could pass through the faces of the refracting angle.

he critical angle of glass is 41° 48′, twice this angle is less than d, accordingly, objects cannot be seen through a glass prism whose ng angle is a right angle. As the critical angle of water is 48° 35 uld pass through a hollow rectangular prism formed of three glass and filled with water.

suppose A to be greater than l and less than $2l$, then of rays in- at I some within the angle NIB will emerge from AC, others will erge, nor will any emerge that are incident within the angle NIA. uppose A to have any magnitude less than l, all rays incident at I the angle NIB will emerge from AC, as also will some of those t within the angle NIA.

Minimum deviation.—When a pencil of solar light passes n an aperture, A, in the side of a dark chamber (fig. 390), the is projected in a straight line, AC, on a distant screen. But if al prism be interposed between the aperture and the screen, the is deviated towards the base of the prism, and the image is pro- at D, at some distance from the point C. If the prism be turned, the incident angle decreases, the luminous disc approaches the , up to a certain position, E, from which it reverts to its original n even when the prism is rotated in the same direction. Hence a deviation, EBC, less than any other. It may be demonstrated natically that this *minimum deviation* takes place when the angles lence and of emergence are equal.

angle of minimum deviation may be calculated when the incident nd the refracting angle of the prism are known. For, when the n is least, as the angle of emergence r' is equal to the incident (fig. 389), r must = i'. But it has been shown above (504) that r'; consequently,

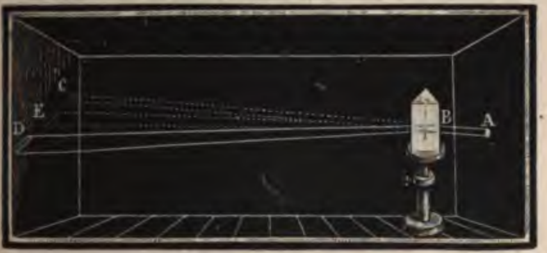


Fig. 390.

$$A = 2r \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If the minimum angle of deviation EDL be called d, this angle b exterior to the triangle DIE, we readily obtain the equation

$$d = i - r + r' - i' = 2i - 2r,$$

whence

$$d = 2i - A \; . \quad . \quad . \quad . \quad . \quad . \quad .$$

which gives the angle d, when i and A are known.

From the formulæ (1) and (2) a third may be obtained, which s to calculate the index of refraction of a prism, when its refracting a and the minimum deviation are known. The index of refraction n i ratio of the sines of the angles of incidence and refraction; h $n = \frac{\sin i}{\sin r}$; replacing i and r from their values in the above equation and (2), we get

$$n = \frac{\sin\left(\frac{A+d}{2}\right)}{\sin\frac{A}{2}} \quad . \quad . \quad . \quad . \quad .$$

506. **Measurement of the index of refraction in solids.**- means of the preceding formula (3) the refractive index of a solid be calculated when the angles A and d are known.

In order to determine the angle A, the substance is cut in the for a triangular prism, and the angle measured by means of a goniom (492).

The angle d is measured in the following manner: a ray, LI, em from a distant object (fig. 391), is received on the prism, which is tu in order to obtain the minimum deviation EDL.′ By means of a scope with a graduated circle, the angle EDL′ is read off, which refracted ray DE makes with the ray DL′, coming directly from

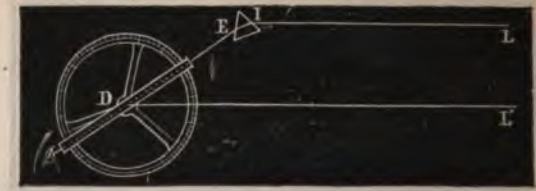


Fig. 391.

object; now this is the angle of minimum deviation, assuming that object is so distant that the two rays LI and L′D are approxima parallel. These values then only need to be substituted in the equa (3) to give the value of n.

This method is due to Newton. Under many circumstances it ca be employed; for instance, when the refractive index of a mere dr fluid is required. In this case, use may be made of a method du Wollaston, which depends on the determination of the critical ang the substance.

Measurement of the index of refraction of liquids.—M. Biot plied Newton's method to determining the refractive index of For this purpose a cylindrical cavity bout 0·75 in. in diameter, is perforated ss prism, PQ (fig. 392), from the in- face to the face of emergence. This s closed by two plates of glass which nented on the sides of this prism. are introduced through a small ed aperture, B. The refracting angle minimum deviation of the liquid in the cavity O having been deter- their values are introduced into the formula (3), which gives the

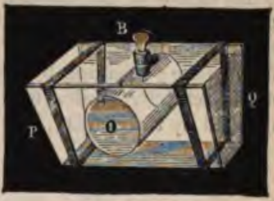


Fig. 392.

Measurement of the index of refraction of gases.—A for this purpose founded on that of Newton has been devised by iot and Arago. The apparatus which they use consists of a glass g. 393), bevelled at its two ends, and closed by glass plates, which an angle of 143°. This tube is connected with a bell-jar, H, h there is a siphon barometer, and with a stopcock by means of the apparatus can be exhausted, fferent gases introduced. After exhausted the tube AB, a ray of A, is transmitted, which is bent om the normal through an angle the first incidence, and towards gh an angle $i'-r'$ at the second. two deviations being added, the eviation d is $r-i+i'-r'$. In e of a minimum deviation, $i=r'$ i', whence $d=\mathrm{A}-2i$, since $r+i'$ 04). The index from vacuum to ch is evidently $\frac{\sin r}{\sin i}$, has therefore ie

$$\frac{\sin\frac{\mathrm{A}}{2}}{\sin\left(\frac{\mathrm{A}-d}{2}\right)} \quad . \quad . \quad . \quad (4)$$

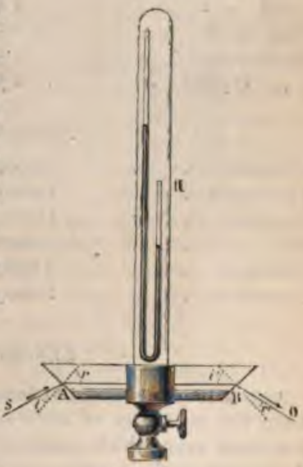


Fig. 393.

e, in order to deduce the refrac- ex from vacuum into air, which is *lute index*, or *principal index*, it is simply necessary to know the g angle A, and the angle of minimum deviation *d*.

tain the absolute index of any other gas, after having produced a this gas is introduced; the angles A and *d* having been mea- e above formula gives the index of refraction from gas to air, the index of refraction from vacuum to air by the index of refraction from the gas to air, we obtain the index of refraction from v to the gas, that is, its absolute index.

By means of this apparatus Biot and Arago have found that the tive indices of gases are very small as compared with those of soli liquids, and that for the same gas the *refractive power is proporti the density*; meaning by the refractive action of a substance the of its refractive index less unity; that is, $n^2 - 1$. The refractive divided by the density, or

$$\frac{n^2 - 1}{d},$$

is called the *absolute refractive power.*

Table of the absolute indices of refraction.

Diamond . . .	2·47 to 2·75	Plate glass, St. Gobin . .	
Phosphorus	2·224	Crown glass	
Sulphur	2·115	Turpentine	
Ruby	1·779	Alcohol	
Bisulphide of carbon .	1·678	Albumen	
Iceland spar, ordinary ray	1·654	Ether	
Iceland spar, extraordinary ray	1·483	Crystalline lens . . .	
		Vitreous „ . . .	
Flint glass	1·575	Aqueous „ . . .	
Rock salt	1·550	Water	
„ crystal	1·548	Ice	

Refractive indices of gases.

Vacuum	1·000000	Carbonic acid . . .	1·0
Hydrogen	1·000138	Hydrochloric acid . .	1·0
Oxygen	1·000272	Nitrous oxide . . .	1·0
Air	1·000294	Sulphurous acid . .	1·0
Nitrogen	1·000300	Olefiant gas . . .	1·0
Ammonia	1·000385	Chlorine	1·0

LENSES. THEIR EFFECTS.

509. **Different kinds of lenses.**—*Lenses* are transparent media, from the curvature of their surfaces, have the property of causin luminous rays which traverse them either to converge or to di According to their curvature they are either *spherical, cylindrical, e cal*, or *parabolic*. Those used in optics are always spherical. Th commonly made either of *crown glass*, which is free from lead, *flint glass*, which contains lead, and is more refractive than glass.

The combination of spherical surfaces, either with each other o plane surfaces, gives rise to six kinds of lenses, sections of whic represented in fig. 394; four are formed by two spherical surface two by a plane and a spherical surface.

is a *double convex*, B is a *plano-convex*, C is a *converging concavo-*
ex, D is a *double concave*, E is a *plano-concave*, and F is a *diverging*
vo-convex. The lens C is also called the *converging meniscus*, and
ns F the *diverging meniscus*.

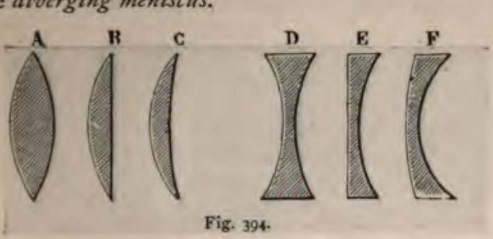


Fig. 394.

e first three, which are thicker at the centre than at the borders, are
rging; the others, which are thinner in the centre, are *diverging*.
e first group, the double convex lens only need be considered, and
second the double concave, as the properties of each of these lenses
to all those of the same group.

lenses whose two surfaces are spherical, the centres for these surfaces
alled *centres of curvature*, and the right line which passes through
two centres is the *principal axis*. In a plano-concave or plano-
ex lens, the principal axis is the perpendicular let fall from the centre
spherical face on the plane face.

order to compare the path of a luminous ray in a lens with that in
sm, the same hypothesis is made as for curved mirrors (483), that is,
urfaces of these lenses are supposed to be formed of an infinity of
plane surfaces or elements; the *normal* at any point is then the
ndicular to the plane of the corresponding element. It is a geo-
cal principle that all the normals to the same spherical surface pass
gh its centre. On the above hypothesis we can always conceive two
surfaces at the points of incidence and convergence, which are in-
d to each other, and thus produce the effect of a prism. Pursuing
comparison, the three lenses A, B, and C may be compared to a
ssion of prisms having their summits outwards, and the lenses D,
d F to a series having their summits inwards; from this we see
he first ought to condense the rays, and the latter to disperse them,
e have already seen that when a luminous ray traverses a prism it
lected towards the base (502).

. **Foci in double convex lenses.**—The focus of a lens is the point
the refracted rays, or their prolongations, meet. Double convex
have the same kind of foci as concave mirrors; that is, real foci
irtual foci.

l foci. We shall first consider the case in which the luminous rays
fall on the lens are parallel to its principal axis, as shown in the
5. In this case, any incident ray, LB, in approaching the normal
point of incidence B, and in diverging from it at the point of emer-
D, is twice refracted towards the axis, which it cuts at F. As all
arallel to the axis are refracted in the same manner, it can be shown

by calculation that they all pass very nearly through the point F, so l
as the arc DE does not exceed 10° to 12°. This point is called
principal focus, and the distance FA is the *principal focal distance*. I
constant in the same lens, but varies with the radii of curvature and

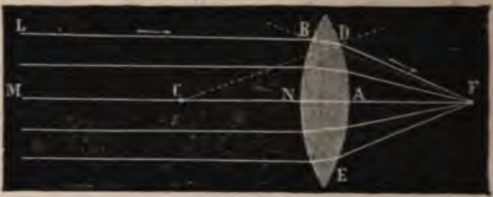


Fig. 395.

index of refraction. In ordinary lenses, which are of crown glass, an
which the radii of the two surfaces are nearly equal, the principal fo
coincides very closely with the centre of curvature.

We shall now consider the case in which the luminous object is outs
the principal focus, but so near that all incident rays form a diverg
pencil, as shown in fig. 396. The luminous point being at L, by compar

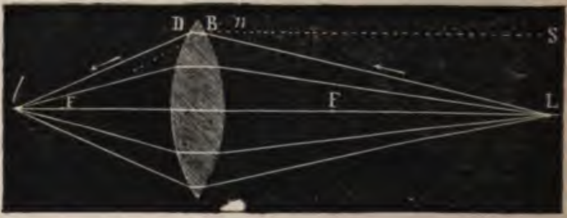


Fig. 396.

the path of a diverging ray, LB, with that of a ray, SB, parallel to
axis, the former is found to make with the normal an angle, LBn, grea
than the angle SBn; consequently, after traversing the lens, the ray c
he axis at a point, l, which is more distant than the principal focus
As all rays from the point L intersect approximately in the same point
this latter is the *conjugate focus* of the point L; this term has the sa
meaning here as in the cases of mirrors, and expresses the relati
existing between the two points L and l, which is of such a nature, that
the luminous point is moved to l, the focus passes to L.

According as the object comes near the lenses, the convergence of
emergent rays decreases, and the focus l becomes more distant; when
object L coincides with the principal focus, the emergent rays on the ot
side are parallel to the axis, and there is no focus, or, what is the sa
thing, it is infinitely distant. As the refracted rays are parallel in
case, the intensity of light only decreases slowly, and a simple lamp

minate great distances. It is merely necessary to place it in the focus a double concave lens, as shown in fig. 397.

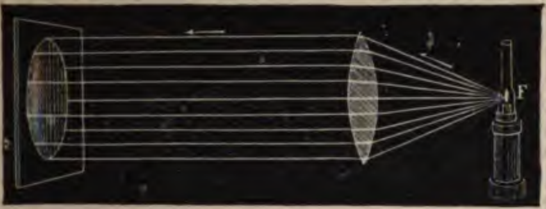


Fig. 397.

irtual foci. A double convex lens has a virtual focus when the inous object is placed between the lens and the principal focus, as wn in fig. 398. In this case the incident rays make with the normal

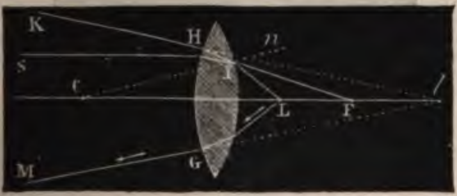


Fig. 398.

ter angles than those made by the rays FI from the principal focus ; ce, when the former rays emerge, they move farther from the axis n the latter, and form a diverging pencil, HK, GM. These rays not produce a real focus, but their prolongations intersect in some nt, *l*, on the axis, and this point is the virtual focus of the point L 7).

11. **Foci in double concave lenses.**—In double concave lenses there only virtual foci, whatever the distance of the object. Let SI be any cil of rays parallel to the axis (fig. 399), any ray, SI, is refracted at the

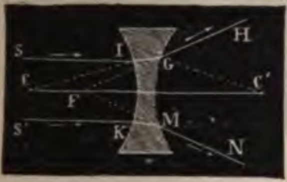


Fig. 399.

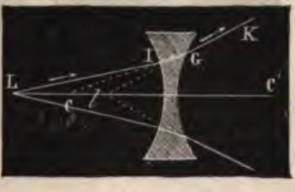


Fig. 400.

t of incidence I, and approaches the normal CI. At the point of emer- e it is refracted, but diverges from the normal GC′, so that it is twice refracted in a direction which moves it from the axis CC′. As the same thing takes place for every other ray, S′KMN, it follows that the rays, after traversing the lens, form a diverging pencil, GH, MN. Hence there is no real focus, but the prolongations of these rays cut one another in a point, F, which is the principal virtual focus.

In the case in which the rays proceed from a point, L (fig. 401), on the axis, it is found by the same construction that a virtual focus is formed at *l*, which is between the principal focus and the lens.

512. **Experimental determination of the principal focus of lenses.**—To determine the principal focus of a double convex lens, it may be exposed to the sun's rays so that they are parallel to its axis. The emergent pencil being received on a ground glass screen, the point to which the rays converge is readily seen ; it is the principal focus.

With a double concave lens, the face *ab* (fig. 401) is covered with an opaque substance, such as lampblack, two small apertures, *a* and *b*, being left in the same principal section, and at an equal distance from the axis ; a pencil of solar light is then received on the other face, and the screen P, which receives the emergent rays, is moved nearer to or farther from the lens, until A and B, the spots of light from the small apertures *a* and *b*, are distant from each other by twice *ab*. The distance DI is then equal to the focal distance FD, because the triangles F*ab* and FAB are similar.

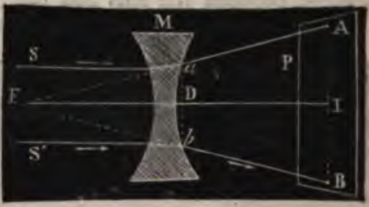


Fig. 401.

513. **Optical centre, secondary axis.**—In every lens there is a point called the *optical centre*, which is situated on the axis, and which has the property that any luminous ray passing through it experiences no angular deviation ; that is, that the emergent ray is parallel to the incident ray. The existence of this point may be demonstrated in the following manner : Let two parallel radii of curvature, CA and C′A′ (fig. 402) be drawn to

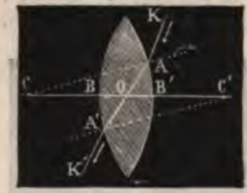


Fig. 402

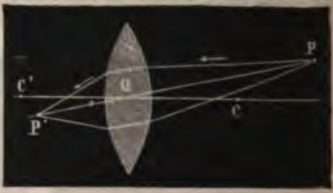


Fig. 403.

the two surfaces of a double convex lens. Since the two plane elements of the lens A and A′ are parallel, as being perpendicular to two parallel right lines, it will be granted that the refracted ray KA, A′K′ is propagated in a medium with parallel faces. Hence, a ray which reaches A at such an inclination, that after refraction it takes the direction AA′, will emerge parallel to its first direction (511); the point O, at which the right line cuts the axis, is therefore the optical centre. The position of this point may be determined for the case in which the curvature of the two faces is the same, which is the usual condition, by observing that the triangles COA and C′OA′ are equal, and therefore that OC = OC′, which gives the point O. If the curvatures are unequal, the triangles COA and C′OA′ are similar, and either CO or C′O may be found, and therefore also the point O.

In double concave or concavo-convex lenses the optical centre may be determined by the same construction. In lenses with a plane face this point is at the intersection of the axis by the curved face.

Every right line, PP′ (fig. 403), which passes through the optical centre without passing through the centres of curvature, is a *secondary axis*. From the property of the optical centre, every secondary axis represents a luminous rectilinear ray passing through this point, for from the slight thickness of the lenses, it may be assumed that rays passing through the optical centre are in a right line; that is, that the small deviation may be neglected which rays experience in traversing a medium with parallel faces (fig. 383).

So long as the secondary axes only make a small angle with the principal axis, all that has hitherto been said about the principal axis is applicable to them; that is, that rays emitted from a point, P (fig. 403), on the secondary axis PP′, nearly converge to a certain point of this axis, P′, and according as the distance from the point P to the lens is greater or less than the principal focal distance, the focus thus formed will be conjugate or virtual. This principle is the foundation of what follows as to the formation of images.

514. **Formation of images in double convex lenses.**—In lenses as well as in mirrors the image of an object is the collection of the foci of its several points; hence the images furnished by lenses are real or virtual in the same case as the foci, and their construction resolves itself into determining a series of points, as was the case with mirrors (486).

i. *Real image.* Let AB (fig. 404) be placed beyond the principal focus. If a secondary axis, A*a*, be drawn from the outside point A, any ray, AC, from this point, will be twice refracted at C and D, and both times in the same direction, approaching the secondary axis, which it cuts at *a*. From what has been said in the last paragraph, the other rays from the point A will intersect in the point *a*, which is accordingly the conjugate focus of the point A. If the secondary axis be drawn from the point B, it will be seen, in like manner, that the rays from this point intersect in the point *b*, and as the points between A and B have their foci between *a* and *b*, a *real* but *inverted* image of AB will be formed at *ab*.

In order to see this image, it may be received on a white scree which it will be depicted, or the eye may be placed in the path of the emerging from it.

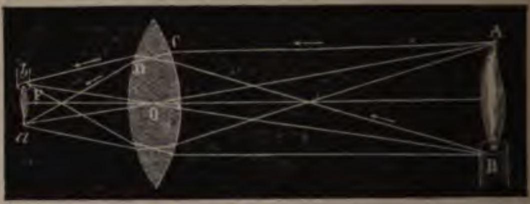


Fig. 404.

Conversely, if *ab* were the luminous or illuminated object emitted rays, its image would be formed at AB. Two conseq important for the theory of optical instruments follow from this 1st, *If an object, even a very large one, is at a sufficient distanc double convex lens, the real and inverted image which is obtained very small, it is near the principal focus, but somewhat farther fr lens than this is ;* 2nd, *If a very small object be placed near the pri focus, but a little before it, the image which is formed is at a great di it is much larger, and that in proportion as the object is nearer th cipal focus.* In all cases the object and the image have the same p tion as their distances from the lens.

These two principles are experimentally confirmed by receivin screen the image of a lighted candle, placed successively at vari tances from a double convex lens.

ii. *Virtual image.* There is another case in which the object AB (fi is placed between the lens and its principal focus. If a secondary a

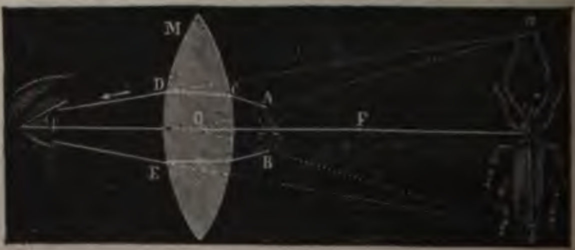


Fig. 405.

be drawn from the point A, every ray, AC, after having been twice re on emerging, diverges from this axis, since the point A is at a les tance than the principal focal distance (510). This ray, continued opposite direction, will cut the axis O*a* in the point *a*, which is the focus of the point A. Tracing the secondary axis of the point B, be found, in the same manner, that the virtual focus of this point is fo at *b*. There is, therefore, an image of AB at *ab*. *This is a virtual image, it is erect, and larger than the object.*

The magnifying power is greater in proportion as the lens is more convex, and the object nearer the principal focus. We shall presently show how the magnifying power may be calculated by means of the formulæ relating to lenses (517). Double convex lenses, used in this manner as magnifying glasses, are called *simple microscopes*.

515. **Formation of images in double concave lenses.**—Double concave lenses, like convex mirrors, only give virtual images, whatever the distance of the object.

Let AB (fig. 406) be an object placed in front of such a lens. If the secondary axis be drawn from the point A, all rays, AC, AI, from this point are twice refracted in the same direction, diverging from the axis AO; so that the eye, receiving the emergent rays DE and GH, supposes them to proceed from the point where their prolongations cut the secondary axis AO in the point *a*. In like manner, drawing a secondary axis from the point B, the rays from this point form a pencil of divergent rays, the directions of which, prolonged, intersect in *b*. Hence the eye sees at *ab* a virtual image of AB, *which is always erect, and smaller than the object.*

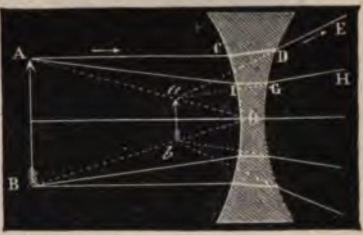


Fig. 406.

516. **Spherical aberration. Caustics.**—In the theory of the foci, and of the images formed by different kinds of spherical lenses, it has been hitherto assumed, that the rays emitted from a single point intersect also after refraction in a single point. This is virtually the case with a lens whose aperture—that is, the angle obtained by joining the edges to the principal focus—does not exceed 10° or 12°.

Where the aperture is larger, the rays which traverse the lens near the edge are refracted to a point nearer the lens than the rays which pass near the axis. The phenomenon thus produced is named *spherical aberration by refraction*; it is analogous to the spherical aberration produced by reflection. The luminous surfaces formed by the intersection of the refracted rays are termed *caustics by refraction*.

Spherical aberration is prejudicial to the sharpness and definition of an image. If a ground glass screen be placed exactly in the focus of a lens, the image of an object will be sharply defined in the centre, but indistinct at the edges; and, *vice versâ*, if the image is sharp at the edges, it will be indistinct in the centre. This defect is very objectionable, more especially n lenses used for photography. It is partially obviated by placing before he lenses diaphragms provided with a central aperture, which admits the ays passing near the centre, but cuts off those which pass near the edges. lso by combining two lenses of suitable curvature, the spherical aberra-on may be destroyed.

517. **Formulæ relating to lenses.**—In all lenses, the relation between the distances of the image and object, the radii of curvature, and the refractive index, may be expressed by a formula. In the case of a double convex lens, let P be a luminous point, situate on the axis fig. 407, let PI

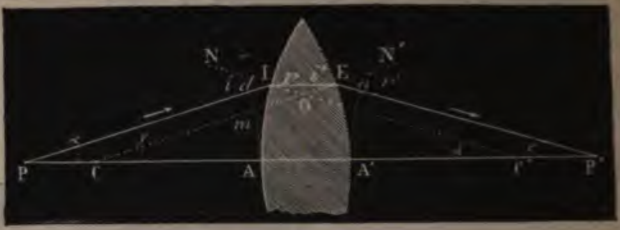


Fig. 407.

be an incident ray, IE its direction within the lens, EP′ the emerg ray, so that P′ is the conjugate focus of P. Further, let C′I and CE the normals to the points of incidence and emergence, and IPA be equal to α, EP′A′ = β, ECA′ = γ, IC′A = δ, NIP = i, EIO = r, IEC N′EP′ = r.

Because the angle i is the exterior angle of the triangle PIC′, an angle r' the exterior angle of the triangle CEP′, therefore, $i = \alpha + \delta$ $r' = \gamma + \beta$, whence

$$i + r' = \alpha + \beta + \gamma + \delta \quad . \quad . \quad . \quad .$$

But at the point I, sin $i = n$ sin r, and at the point E, sin $r' = n$ sin i' n being the refractive index of the lens. Now if the arc AI is a small number of degrees, these sines may be considered as propor to the angles i, r, i', and r', whence, in the above formula, we may re the sines by their angles, which gives $i = nr$ and $r' = ni'$, from $i + r' = n\ (r + i')$. Further, because the two triangles IOE and COC a common equal angle, O, therefore $r + i' = \gamma + \delta$, from which $i +$ $(\gamma + \delta)$. Introducing this value into the equation (1) we obtain

$$n\ (\gamma + \delta) = \alpha + \beta + \gamma + \delta, \text{ from which } (n - 1)\ (\gamma + \delta) = \alpha + \beta \ . \quad .$$

Let CA′ be denoted by R, C′A by R′, PA by p, and P′A′ by p'. with centre P and radius PA describe the arc Ad, and with centre P radius P′A′ describe the arc An. Now when an angle at the centr circle subtends a certain arc of the circumference, the quotient of th divided by the radius measures the angle; consequently,

$$\alpha = \frac{\mathrm{A}d}{\mathrm{PA}} \text{ or } \frac{\mathrm{A}d}{p}, \beta = \frac{\mathrm{A}'n}{p'}, \gamma = \frac{\mathrm{A'E}}{\mathrm{R}}, \text{ and } \delta = \frac{\mathrm{AI}}{\mathrm{R}'}.$$

Therefore by substitution in (2)

$$(n - 1) \left(\frac{\mathrm{A'E}}{\mathrm{R}} + \frac{\mathrm{AI}}{\mathrm{R}'} \right) = \frac{\mathrm{A}d}{p} + \frac{\mathrm{A}'n}{p}.$$

Now since the thickness of the lens is very small, and the angles also small, and Ad, AI, A′E, A′n differ but little from coincident strai

and are therefore virtually equal. Hence the above equation be-
s

$$(n-1)\left(\frac{1}{R}+\frac{1}{R'}\right)=\frac{1}{p}+\frac{1}{p'} \quad . \quad . \quad . \quad . \quad (3)$$

is the formula for double convex lenses ; if p be $=\infty$, we have

$$(n-1)\left(\frac{1}{R}+\frac{1}{R'}\right)=\frac{1}{p'}$$

ng the principal focal distance. If this be represented by f, we get

$$(n-1)\left(\frac{1}{R}+\frac{1}{R'}\right)=\frac{1}{f} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

which the value of f is easily deduced. Considered in reference to
a (4), the formula (3) assumes the form

$$\frac{1}{p}+\frac{1}{p'}=\frac{1}{f} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

is that in which it is usually employed. When the image is virtual,
its sign, and formula (5) takes the form

$$\frac{1}{p}-\frac{1}{p'}=\frac{1}{f} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

ncave lenses, p' and f retain the same sign, but that of p
rmula (5) becomes then

$$\frac{1}{p}-\frac{1}{p'}=-\frac{1}{f} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

may be obtained by the same reasonings as the other.

—As an application of lenses may be adduced the
hich is an instrument recently invented to facilitate the
f the larynx and the other cavities of the mouth. It con-

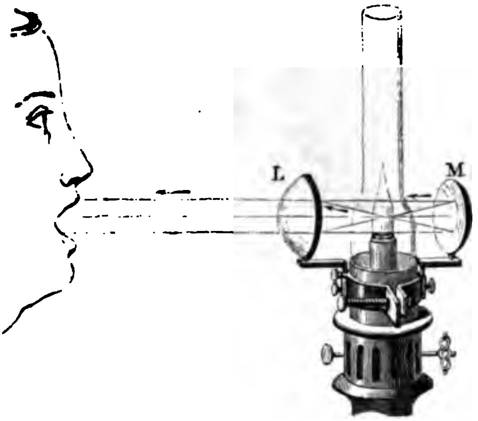


Fig. 408.

of a plane convex lens L, and a concave reflector M, both fixed to a ring which can be adjusted to any convenient lamp. The flame of lamp is in the principal focus of the lens, and at the same time is a centre of curvature of the reflector. Hence the divergent pencil procee from the lamp to the lens is changed after emerging into a par pencil. Moreover, the pencil from the lamp impinging upon the mi is reflected to the focus of the lens, and traverses the lens formin second parallel pencil which is supported on the first. This being dire into the mouth of a patient, its condition may be readily observed.

CHAPTER IV.

DISPERSION AND ACHROMATISM.

519. **Decomposition of white light. Solar spectrum.**—The ph menon of refraction is by no means so simple as we have hitherto sumed; when *white* light, or that which reaches us from the sun, pa from one medium into another, *it is decomposed into several kind lights*, a phenomenon to which the name *dispersion* is given.

In order to show that white light is decomposed by refraction, a pe of solar light, SA (fig. 409). is allowed to pass through a small aper

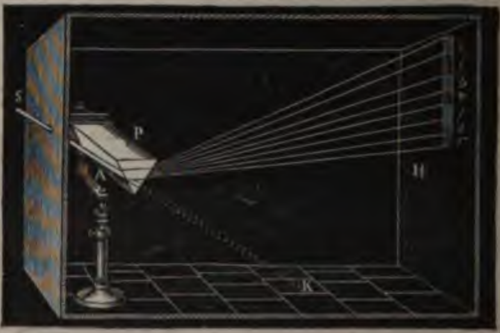


Fig. 409.

in the window shutter of a dark chamber. This pencil tends to fo round and colourless image of the sun at K; but if a flint glass pri arranged horizontally, be interposed in its passage, the beam, on emerg from the prism, becomes refracted towards its base, and produces o distant screen a vertical band, coloured in all the tints of the rainb which is called the *solar spectrum*, see plate I. In this spectrum th is, in reality, an infinity of different tints, which imperceptibly merge i each other, but it is customary to distinguish seven principal colours. Th are *violet, indigo, blue, green, yellow, orange, red*; they are arranged this order in the spectrum, the violet being the most refrangible, and the red the least so. They do not all occupy an equal extent in the spectrum, violet having the greatest extent, and orange the least.

With transparent prisms of different substances, or with hollow glass prisms filled with various liquids, spectra are obtained formed of the same colours, and in the same order; but when the deviation produced is the same, the length of the spectrum varies with the substance of which the prism is made. The angle of separation of two selected rays (say in the red and the violet) produced by a prism is called the *dispersion*, and the ratio of this angle to the mean deviation of the two rays is called the *dispersive power*. This ratio is constant for the same substance so long as the refracting angle of the prism is small. For the deviations of the two rays are proportional to the refracting angle; their difference and their mean vary in the same manner, and, therefore, the ratio of their difference to their mean is constant. For flint glass this is 0·043; for crown glass it is 0·0246; for the dispersive power of flint is almost double that of crown glass.

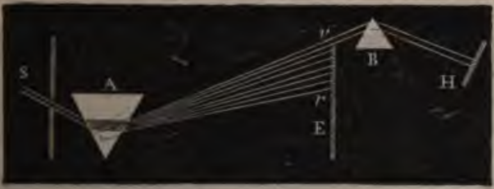


Fig. 410.

The spectra which are formed by artificial lights rarely contain all the colours of the solar spectrum; but their colours are found in the solar spectrum, and in the same order. Their relative intensity is also modified. The shade of colour which predominates in the flame predominates also in the spectrum: yellow, red, and green flames produce spectra in which the dominant tint is yellow, red, or green.

In order to produce a solar spectrum in which the seven principal tints are distinctly seen, the aperture by which light enters ought not to be more than a few millimeters in diameter, and if the refracting angle of the prism, as is usually the case, is 60°, the screen on which the spectrum is caught must be 5 or 6 yards distant.

520. **The colours of the spectrum are simple, and unequally refrangible.**—If one of the colours of the spectrum be isolated by intercepting the others by means of a screen, E, as shown in fig. 410, and if the light thus intercepted be allowed to pass through a second prism, B, a refraction will be observed, but the light remains unchanged; that is, the image received on the screen H is violet if the violet pencil has been allowed to pass, blue if the blue pencil, and so on. Hence the colours of the spectrum are *simple*; that is, they cannot further be decomposed by the prism.

Moreover, the colours of the spectrum are unequally refrangible; that is, they possess different refractive indices. The elongated shape of the spectrum would be sufficient to prove the unequal refrangibility of the simple colours, for it is clear that the violet, which is most deflected towards the base of the prism, is also most refrangible, and that red which is least deflected is least refrangible. But the unequal refrangibility of simple colours may be shown by numerous experiments, of which the two following may be adduced :—

i. Two narrow strips of coloured paper, one red and the other violet, are fastened close to each other on a sheet of black paper. On looking at them through a prism, they are seen to be unequally displaced, the red band to a less extent than the violet; hence the red rays are less refrangible than the violet.

ii. The same conclusion may be drawn from Newton's experiment with crossed prisms. On a prism, A (fig. 411), in a horizontal position, a pencil of white light, S, is received, which, if it had merely traversed the prism A, would form the spectrum *rv*, on a distant screen. But if a second prism, B, be placed in a vertical position behind the first, in such a manner that the refracted pencil passes through it, the spectrum *rv* becomes deflected towards the base of the vertical prism : but, instead of being deflected in a direction parallel to itself, as would be the case if the colours of the spectrum were equally refracted, it is obliquely refracted in the direction *r′v′*, proving that from red to violet the colours are more and more refrangible.

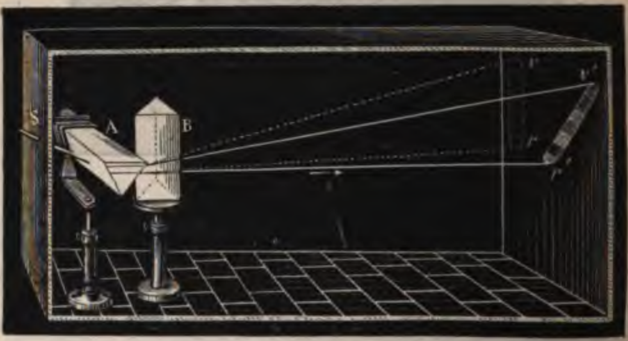


Fig. 411.

These different experiments show that the refractive index differs in different colours; even rays which are to perception undistinguishable have not the same refractive index. In the red band, for instance, the rays at the extremity of the spectrum are less refracted than those which are nearer the orange zone. In calculating indices of refraction (496), it is usual to take as the index of any particular substance the refrangibility of the yellow ray in a prism formed of that substance.

521. **Recomposition of white light.**—Not merely can white light be

olved into lights of various colours, but by combining the different ncils separated by the prism, white light can be reproduced. This may effected in various ways :—

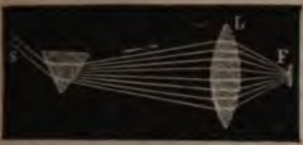


Fig. 412.

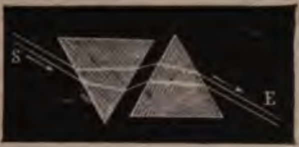


Fig. 413.

i. If the spectrum produced by one prism be allowed to fall upon a cond prism of the same material, and the same refracting angle as the st, but inverted, as shown in fig. 413, the latter reunites the different lours of the spectrum, and it is seen that e emergent pencil E, which is parallel the pencil S, is colourless.

ii. If the spectrum falls upon a double nvex lens (fig. 412), a white image of e sun will be formed on a white screen aced in the focus of the lens; a glass obe filled with water produces the same fect as the lens.

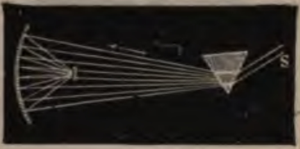


Fig. 414.

iii. When the spectrum falls upon a concave mirror, a white image formed on a screen of ground glass placed in its focus (fig. 414).

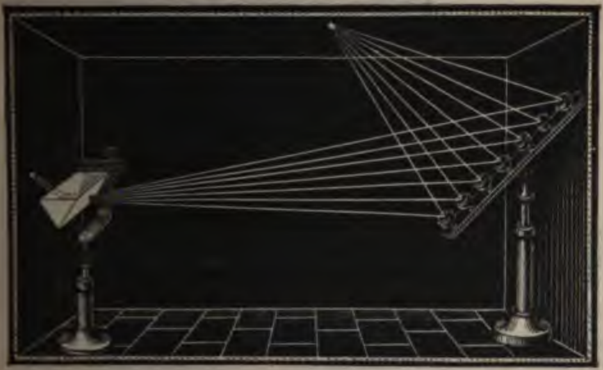


Fig. 415.

. Light may be recomposed by means of a pretty experiment, which sists in receiving the seven colours of the spectrum on seven small s mirrors with plane faces, and which can be so inclined in all tions that the reflected light may be transmitted in any given direc- (fig. 415). When these mirrors are suitably arranged, the seven reflected pencils may be caused to fall on the ceiling in such a man as to form seven distinct images—red, orange, yellow, etc. When mirrors are moved so that the separate images become superposed single image is obtained, which is white.

v. By means of *Newton's disc*, it may be shown that the seven col of the spectrum form white. This is a cardboard disc of about a foot diameter; the centre and the edges are covered with black paper, w in the space between there are pasted strips of papers of the colours the spectrum. They proceed from the centre to the circumference, their relative dimensions and tints are such as to represent five spec (fig. 416). When this disc is rapidly rotated, the effect is the same

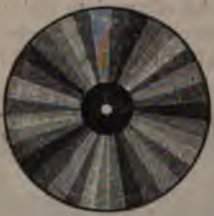


Fig. 416.

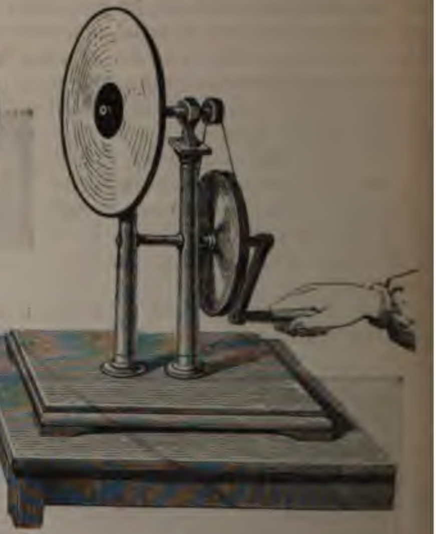


Fig. 417.

the retina received simultaneously the impression of the seven colo This depends on the physiological fact, that sensation always lasts a l longer than the impression from which it results. If a new impres is allowed to act, before the sensation arising from the former one ceased, a sensation is obtained consisting of two impressions. And choosing the time short enough, three, four, or more impressions may mixed with each other. With a rapid rotation the disc is nearly w It is not quite so, for the colours cannot be exactly arranged in the s proportions as those in which they exist in the spectrum, and *pigm* colours are not pure.

522. **Newton's theory of the composition of light.**—Newton was first to decompose white light by the prism, and to recompose it. F the various experiments which we have described, he concluded

light was not homogeneous, but formed of seven lights unequally ngible, which he called *simple* or *primitive* lights. Owing to their ence in refrangibility they become separated in traversing the ı.

e designation of the various colours of the spectrum is to a very extent arbitrary; for in strict accuracy, the spectrum is made up of finite number of simple colours, which pass into one another by ceptible gradations of colour and refrangibility.

. **Colour of bodies.**—The natural colour of bodies results from the hat of the coloured rays contained in white light, one portion is bed at the surface of the body. If the unabsorbed portion traverses ody, it is coloured and transparent; if, on the contrary, it is reflected, coloured and opaque. In both cases the colour results from the ituents which have not been absorbed. Those which reflect or mit all colours in the proportion in which they exist in the spectrum white; those which reflect or transmit none are black. Between two limits there are infinite tints according to the greater or less t to which bodies reflect or transmit some colours and absorb s. Thus a body appears yellow, because it absorbs all colours with xception of yellow. In like manner, a solution of ammoniacal oxide of er absorbs preferably the red and yellow rays, transmits the blue almost completely, the green and violet less so, hence the light seen gh it is blue.

nce bodies have no colour of their own; with the nature of the ent light the colour of the body changes. Thus, if in a dark room, ite body be successively illuminated by each of the colours of the rum, it has no special colour but appears red, orange, green, etc., rding to the position in which it is placed. If homogeneous light upon a body, it appears brighter in the colour of this light, if it does bsorb this colour; but black if it does absorb it. In the light of a fed by spirit in which some common salt is dissolved, everything and yellow seems bright, while the most of the other colours are . In the light of lamps and of candles, which from the want of blue appear yellow, yellow and white appear the same, and blue seems green. In bright twilight or in moonshine, the light of gas has a sh tint.

. **Mixed colours. Complementary colours.**—By mixed colours we rstand the impression of colour which results from the coincident n of two or more colours on the same position of the retina. This mpression is single; it cannot be resolved into its components; in espect it differs from a complex sound in which the ear by practice listinguish the constituents. Mixed colours may be produced by ng different parts of the spectrum to cover each other; they may also oduced by looking in an oblique direction through a vertical glass at a coloured surface; while at the same time, the observer's side of late reflects towards his eye light of a different colour. The method coloured disc affords another means of producing mixed colours.

in any of the methods by which the impression of mixed spectral colours is produced, one or more colours be suppressed, the residue corresponds to one of the tints of the spectrum; and the mixture of the colours taken away produces the impression of another spectral colour. Thus, if in fig. 411 the red rays are cut off from the lens L, the light on the focus is no longer white but greenish blue. In like manner if the violet, indigo, and blue of the colour disc be suppressed, the rest seems yellow, while the mixture of that which has been taken out is a bluish violet. Hence white can always be compounded of *two* tints; and two tints which together give white are called *complementary colours.* Thus of spectral tints *red* and *greenish yellow* are complementary, so are *orange* and *prussian blue*; *yellow* and *indigo blue*; *greenish yellow* and *violet.*

A distinction must be made between *spectral colours* and *pigment colours.* Thus a mixture of pigment yellow and pigment blue produces green and not white, as is the case when the blue and yellow of the spectrum are mixed. The reason of this is that in the mixture of pigments we have a case of subtraction of colours and not of addition. For in the mixture the pigment blue absorbs almost entirely the yellow and red light; and the pigment yellow absorbs the blue and violet light so that only the green remains.

If the complementary spectral colours are mixed in other proportions than is requisite for the production of white, intermediate colours are obtained which lie in the spectrum between the tints of the complementary colours. Thus a mixture of red and greenish blue, in which the former predominates, produces a tint which is nearer orange; while when the latter is in excess, the tint comes nearer yellow and ultimately green. These colours, however, are not so pure as the corresponding spectral tints. They are less *saturated*, as it is called; that is, mixed with white.

In the above series are two spectral colours very remote in the spectrum which have nearly the same complementary colours: these are red, the complementary colour to which is greenish blue, and violet, whose complementary colour is greenish yellow. Now when two pairs of complementary colours are mixed together, they must produce white just as if only two complementary colours were mixed. But a mixture of greenish blue and of greenish yellow is green. Hence it follows that from a mixture of red, green, and violet white must be formed. This may easily be ascertained to be the case, by means of a colour disc on which are these three colours in suitable proportions.

From the above facts it follows that from a mixture of red, green, and violet all possible colours may be constructed, and hence these three spectral colours are called the *fundamental colours.* It must be remarked that the tints resulting from the mixture of these three have never the saturation of the individual spectral colours.

We have to discriminate three points in regard to *colour.* In the first place, the *tint* or colour proper by which we mean that special property which is due to a definite refrangibility producing it; secondly, the *saturation* which depends on the greater or less admixture of white light with the spectrum, these being colours which are fully saturated; there is the *intensity* which depends on the amplitude of

geneous light.—The light emitted from luminous bodies never quite pure, on being examined by the prism it will be tain more than one colour. In optical researches it is fre- eat importance to procure *homogeneous* or *monochromatic* non salt in the flame of a Bunsen's lamp gives a yellow of For red light, ordinary light is transmitted through glass suboxide of copper, which absorbs nearly all the rays ex- ed. A very pure blue is obtained by transmitting ordinary a glass trough with parallel sides, containing an ammoniacal lphate of copper.

rties of the spectrum.—Besides its luminous properties, is found to produce calorific and chemical effects.

properties. It appears from the experiments of Fraunhofer hel, that the light in the yellow part of the spectrum has ntensity, and that in the violet the least.

ects. It was long known that the various parts of the ered in their calorific effects. Leslie found that a thermo- in different parts of the spectrum indicated a higher tem- it moved from violet towards red. Herschel fixed the ensity of the heating effects just outside the red; Berard lf. Seebeck showed that those different effects depend on a prism: with a prism of water the greatest calorific effect the yellow; with one of alcohol it is in the orange-yellow; ism of crown glass it is in the middle of the red.

using prisms and lenses of rock salt, and by availing him- treme delicacy of the thermo-electric apparatus, first made vestigation of the calorific properties of the thermal spec- esult led, as we have seen, to the confirmation and extension bservations.

roperties. In numerous phenomena, light acts as a chemical instance, chloride of silver blackens under the influence of rent phosphorus becomes opaque, vegetable colouring hydrogen and chlorine gases, when mixed, combine slowly ight, and with explosive violence when exposed to direct e chemical action differs in different parts of the spectrum. that when chloride of silver was placed in the violet, the ore energetic than in any other part. Wollaston observed n extended beyond the violet, and concluded that, besides ys, there are some invisible and more highly refrangible are the chemical or *actinic* rays.

ches of Bunsen and Roscoe show that whenever chemical ced by light, an absorption of light takes place, preferably refrangible parts of the spectrum. Thus, when chlorine unite, under the action of light, to form hydrochloric acid light is absorbed, and the quantity of chemically active rays consumed is directly proportional to the amount of chemical action.

There is a curious difference in the action of the different rays. Moser placed an engraving on an iodized silver plate, and exposed it to the light until an action had commenced, and then placed it under a violet glass in the sunlight. After a few minutes a picture was seen with great distinctness, while when placed under a red or yellow glass it required a very long time, and was very indistinct. When, however, the iodized silver plate was first exposed in a camera obscura to blue light for two minutes, and was then brought under a red or yellow glass, an image quickly appeared, but not when placed under a green glass. It appears as if there are vibrations of a certain velocity which could commence an action and that there are others which are devoid of the property of commencing, but can continue and complete an action when once set up. Becquerel, who discovered these properties in luminous rays, called the former *exciting rays*, and the latter *continuing* or *phosphorogenic rays*. The phosphorogenic rays, for instance, have the property of rendering certain objects self-luminous in the dark after they have been exposed for some time to the light. Becquerel found that the phosphorogenic spectrum extended from indigo to beyond the violet.

527. **Dark lines of the spectrum.**—The colours of the solar spectrum are not continuous. For several grades of refrangibility rays are wanting, and in consequence, throughout the whole extent of the spectrum, there are a great number of very narrow dark lines. To observe them, a pencil of solar rays is admitted into a darkened room, through a narrow slit. At a distance of three or four yards, we look at this slit through a prism of flint glass, which must be very free from flaws, taking care to hold its edge parallel to the slit. We then observe a great number of very delicate dark lines parallel to the edge of the prism, and at very unequal intervals.

The existence of the dark lines was first observed by Wollaston in 1802; but Fraunhofer, a celebrated optician of Münich, first studied and gave a detailed description of them. Fraunhofer mapped the lines, and indicated the most marked of them by the letters A, *a*, B, C, D, E, *b*, F, G, H; they are therefore generally known as Fraunhofer's lines.

The dark line A (see fig. 2 of plate I.), is at the extremity and B in the middle of the red ray; C at the boundary of the red and orange ray; D is in the yellow ray; E, in the green; F, in the blue; G, in the indigo; H, in the violet. There are certain other noticeable dark lines, such as *a* in the red, and *b* in the green. In the case of solar light the positions of the dark lines are fixed and definite; on this account they are used for obtaining an exact determination of the refractive index (506) of each colour; for example, the refractive index of the blue ray is, strictly speaking, that of the dark line F. In the spectra of artificial lights, and of the stars, the relative positions of the dark lines are changed. In the electric light the dark lines are replaced by brilliant lines. In coloured flames, that is to say, flames in which certain chemical substances undergo evaporation, the dark lines are replaced by very

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liant lines of light, which differ for different substances. Lastly, of dark lines, some are constant in position and distinctness, such are unhofer's lines ; but some of the lines only appear as the sun nears horizon, and others are strengthened. They are also influenced by state of the atmosphere. The fixed lines are due to the sun ; the iable lines have been proved by Jannsen and Secchi to be due to the eous vapour in the air, and are called atmospheric or *telluric* lines.

raunhofer counted in the spectrum more than 600 dark lines, more or distinct, distributed irregularly from the extreme red to the extreme let ray. Brewster counted 2,000. By causing the refracted rays to

opening whereby the light of the flame G enters the telescope B, sists of a narrow vertical slit, which can be opened more or less by ing the moveable piece *a* to adce or recede by means of the w *v* (fig. 420). When for purs of comparison two spectra are e examined simultaneously, there laced over the upper part of the a small prism, whose refracting le is 60°. Rays from one of the nes, H, fall at right angles on one e of the prism, they then experie total reflection on a second face, l leave the prism by the third face, l in a direction at right angles to e face. By this means they pass into telescope in a direction parallel to its axis, without in any degree mixing h the rays which proceed from the second flame, G. Consequently, two pencils of rays traverse the prism P (fig. 419), and form two horital spectra which are viewed simultaneously through the telescope A. he flames G and H are platinum wires, *e*, *e'*. These wires have been ed beforehand into solutions of the salts of the metals on which

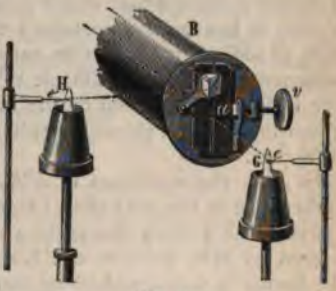

Fig. 420.

Fig. 418.

ss successively through several analysing prisms, not merely has the stence of 3,000 dark lines been ascertained, but several which had been posed single have been shown to be double.

28. **Applications of Fraunhofer's lines.**—Subsequently to Fraunfer, several physicists studied the dark lines of the spectrum. In 1822 J. Herschel remarked that by volatilising substances in a flame a very icate means is afforded of detecting certain ingredients by the colours y impart to certain of the dark lines of the spectrum ; and Fox Talbot 834 suggests optical analysis as probably the most delicate means of ecting minute portions of a substance. To Kirchhoff and Bunsen, ever, is really due the merit of basing on the observation of the lines e spectrum a method of analysis. They ascertained that the salts e same metal, when introduced into a flame, always produce lines tical in colour and position, but different in colour, position, or num-

ber for different metals, and finally that an exceedingly small quantity of a metal suffices to disclose its existence. Hence has arisen a new method of analysis, known by the name of *spectral analysis*.

529. **Spectroscope.**—The name of spectroscope has been given to the apparatus employed by Kirchhoff and Bunsen for the study of the spectrum. One of the forms of this apparatus is represented in fig. 406. It is composed of three telescopes mounted on a common foot, and whose axes converge towards a prism, P, of flint-glass. The telescope A is the only one which can turn round the prism. It is fixed in any required position by a clamping screw, *n*. The screw-head, *m*, is used to shift the quickly appeared, but not when placed under of the spectrum may b as if there are vibrations of a certain velocity which could commence action and that there are others which are devoid of the property commencing, but can continue and complete an action when once set Becquerel, who discovered these properties in luminous rays, called former *exciting rays*, and the latter *continuing* or *phosphorogenic* The phosphorogenic rays, for instance, have the property of render certain objects self-luminous in the dark after they have been expos for some time to the light. Becquerel found that the phosphoroge spectrum extended from indigo to beyond the violet.

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The existence of the dark lines was first observed by Wollaston 1802; but Fraunhofer, a celebrated optician of Münich, first studied

Fig. 419.

divided into 25 equal parts. The micrometer is formed thus:—A scale of 250 millimeters is divided with great exactness into 25 equal parts. A photographic negative on glass of this scale is taken, reduced to 15 millimeters. The negative is taken because then the scale is light on a dark ground. The scale is then placed at *m* in the principal focus of the lens *e*; consequently, when the scale is lighted by the candle

, the rays emitted from it leave the lens e in parallel pencils ; a portion f these, being reflected from a face of the prism, passes through the lens . and forms a perfectly distinct image of the micrometer at i, thereby rnishing the means of measuring exactly the relative distances of the fferent spectral lines.

The micrometric telescope C (fig. 418) is furnished with several adjust-g screws, i, o, r : of these i adjusts the focus ; o displaces the micro-eter in the direction of the spectrum laterally ; r raises or lowers e micrometer, which it does by giving different inclinations to the lescope.

The opening whereby the light of the flame G enters the telescope B, nsists of a narrow vertical slit, which can be opened more or less by using the moveable piece a to ad-ance or recede by means of the rew v (fig. 420). When for pur-ses of comparison two spectra are be examined simultaneously, there placed over the upper part of the t a small prism, whose refracting gle is 60°. Rays from one of the mes, H, fall at right angles on one ce of the prism, they then experi-ce total reflection on a second face, d leave the prism by the third face, d in a direction at right angles to at face. By this means they pass into e telescope in a direction parallel to its axis, without in any degree mixing th the rays which proceed from the second flame, G. Consequently, e two pencils of rays traverse the prism P (fig. 419), and form two hori-ntal spectra which are viewed simultaneously through the telescope A. the flames G and H are platinum wires, e, e'. These wires have been pped beforehand into solutions of the salts of the metals on which periment is to be made; and by the vaporisation of these salts the etals modify the transmitted light, and gave rise tc definite lines.

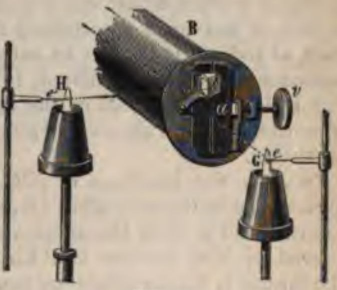

Fig. 420.

Each of the flames H and G is a jet of ordinary gas. The apparatus rough which the gas is supplied is known as a *Bunsen's burner*. The s comes through the hollow stem k (fig. 418). At the lower part of s there is a lateral orifice to admit air to support the combustion of e gas. This orifice can be more or less closed by a small diaphragm, ich acts as a regulator. If we allow a moderate amount of air to enter, e gas burns with a luminous flame, and the lines are obscured. But if trong and steady current of air enters, the carbon is rapidly oxidised, flame loses its brightness, and burns with a pale blue light, but with intense heat. In this state it no longer yields a spectrum. If, how-r, a metallic salt is introduced either in a solid state or in a state of ution, the spectrum of the metal makes its appearance, and in a fit e for observation.

here are three chief types of spectra : the *continuous* spectrum, or those furnished by ignited solids and liquids (fig. 1, Plate I.); the *band* or *line* spectrum, consisting of a number of bright lines, and produced by ignited gases or vapours; and *absorption* spectra, or those furnished by the sun or fixed stars. For an explanation of these, see art. 531. Bodies at a red heat give only a small spectrum, extending at most to the orange; as the temperature gradually rises, yellow, green, blue, and violet successively appear, while the intensity of the lower colours increases.

530. **Experiments with the spectroscope.**—The coloured plate at the beginning shows certain spectra observed by means of the spectroscope. No 1 represents the continuous spectrum.

No. 2 shows the spectrum of sodium. This spectrum contains neither red, orange, green, blue, nor violet. It is marked by a very brilliant yellow ray in exactly the same position as Fraunhofer's dark line D. Of all metals sodium is that which possesses the greatest spectral sensibility. In fact, it has been ascertained that one two hundred millionth of a grain of sodium is enough to cause the appearance of the yellow line. Consequently, it is very difficult to avoid the appearance of this line. A very little dust scattered in the apartment is enough to produce it,—a circumstance which shows how abundantly sodium is distributed throughout nature.

No. 3 is the spectrum of *lithium*. It is characterised by a well-marked line in the red called Liα, and by a feebler orange line Liβ.

Nos. 4 and 5 show the spectra of *cæsium* and *rubidium*, metals discovered by MM. Bunsen and Kirchhoff by means of spectral analysis. The former is distinguished by two blue lines Csα and Csβ, the latter by two very brilliant dark red lines Rbγ and Rbδ, and by two less intense violet lines Rbα and Rbβ. A third metal, *thallium*, has been discovered by the same method by Mr. Crookes in England, and independently by M. Lamy in France. Thallium is characterised by a single green line. Still more recently Richter and Reich have discovered a new metal associated with zinc, and which they call *indium* from a couple of characteristic lines which it forms in the indigo.

The extreme delicacy of the spectrum reactions, and the ease with which they are produced, constitute them a most valuable help in the quantitative analysis of the alkalies and alkaline earths. It is sufficient to place a small portion of the substance under examination on platinum wire as represented in fig. 420, and compare the spectrum thus obtained either directly with that of another substance, or with the charts in which the positions of the lines produced by the various metals are laid down.

With other metals the production of their spectrum is more difficult, especially in the case of some of their compounds. The heat of a Bunsen's burner is insufficient to vaporise the metals, and a more intense temperature must be used. This is effected by taking electric sparks between wires consisting of the metal whose spectrum is required, and the electric sparks are most conveniently obtained by means of Ruhmkorff's coil. Thus all the metals may be brought within the sphere of spectrum observations.

The power of the apparatus has great influence on the nature of the pectrum; while an apparatus with one prism only gives in a sodium flame he well-known yellow line, an apparatus with more prisms resolves it into wo or three lines.

It has been observed that the character of the spectrum changes with e temperature; thus chloride of lithium in the flame of a Bunsen's rner gives a single intense peach-coloured line; in a hotter flame, as at of hydrogen, it gives an additional orange line; while in the oxy-drogen jet or the voltaic arc a broad brilliant blue band comes out in ldition. The sodium spectrum produced by a Bunsen's burner con-sts of a single yellow line; if, by the addition of oxygen, the heat be gra-ally increased, more bright lines appear; and with the aid of the oxy-drogen flame the spectrum is continuous. Sometimes also, in addition the appearance of new lines, an increase in temperature resolves those *nds* which exist into a number of fine *lines*, which in some cases are ore and in some less refrangible than the bands from which they are rmed. It may be supposed that the glowing vapour found at the low nperature consists of the oxide of some difficultly reducible metal, ereas at the enormously high temperature of the spark these com-unds are decomposed, and the true bright lines of the metal are rmed.

The delicacy of the reaction increases very considerably with the tem-rature. With the exception of the alkalies, it is from 40 to 300 times eater at the temperature of the electric spark than at that of Bunsen's rner.

The spectra of the permanent gases are best obtained by taking the ctric spark of a Ruhmkorff's coil, or Holtz's apparatus, through glass es of a special construction, provided with electrodes of platinum and ed with the gas in question in a state of great attenuation, known as *issler's tubes*; if the spark be passed through hydrogen, the light emitted bright red, and its spectrum consists of one bright red, one green, and e blue line No. 7, the first two of which appear to coincide with Fraun-fer's lines C and F, and the third with a line between F and G. . 6 represents the spectrum of oxygen. No. 8 is the spectrum of rogen. The light of this gas in a Geissler's tube is purple and the ctrum very complicated.

f the electric discharge takes place through a compound gas or oour, the spectra are those of the elementary constituents of the gas. seems as if at very intense temperatures chemical combination was possible, and oxygen and hydrogen, chlorine and the metals, could xist in a separate form, although mechanically mixed with each other.

he nature of the spectra of the elementary gases is very materially uenced by alterations of temperature and pressure. Wüllner made a es of very accurate observations on the gases oxygen, hydrogen, and ogen. He not only used gases in closed tubes, which by various trical means he raised to different temperatures; but in one and the e series of experiments, in which a small inductorium was used, he loyed pressures varying from 100 millimeters to a fraction of a milli-er; while, in another series, in which a larger apparatus was used, he extended the pressure to 2,000 millimeters. At the lowest pressure of less than 1 millimeter, the spectrum of hydrogen was found to be green, and consisting of six splendid groups of lines, which at a higher pressure than 1 millimeter changed to continuous bands; at 2 to 3 millimeters the spectrum consisted of the often-mentioned three lines, which did not disappear under a higher pressure, but gradually became less brilliant as the continuous spectrum increased in extent and lustre. From this point the light, and therefore the spectrum, became feebler. Using the larger apparatus, the band spectrum appeared only under a higher pressure; at the highest pressure of 2,000 millimeters it gave place to the continuous spectrum, since the bright lines continually extended and ultimately merged into each other.

531. **Explanation of the dark lines of the solar spectrum.**—It has been already seen that incandescent sodium vapour gives a bright yellow line corresponding to the dark line D of the solar spectrum. Kirchhoff found that, when the brilliant light produced by incandescent lime passes through a flame coloured by sodium in the usual manner, a spectrum is produced in which is a dark line coinciding with the dark line D of the solar spectrum; what would have been a bright yellow line becomes a dark line when formed on the background of the lime light. By allowing in a similar manner the lime light to traverse vapours of potassium, barium, strontium, etc., the bright lines which they would have formed were found to be converted into dark lines: such spectra are called absorption spectra.

It appears then that the vapour of sodium has the power of absorbing rays of the same refrangibility as that which it emits. And the same is true of the vapours of potassium, barium, strontium, etc. This absorptive power is by no means an isolated phenomenon. These substances share it, for example, with the vapour of nitrous acid, which Brewster found to possess the following property: when a tube filled with this vapour is placed in the path of the light either of the sun or of a gas flame, and the light is subsequently decomposed by a prism, a spectrum is produced which is full of dark lines (No. 9, Plate I.); and Miller showed that iodine and bromine vapour produced analogous effects.

Hence the origin of the above phenomenon is, doubtless, the absorption by the sodium vapour of rays of the same kind, that is, of the same refrangibility, as those which it has itself the power of emitting. Other rays it allows to pass unchanged, but these it either totally or in great part suppresses. Thus the particular lines in the spectrum to which these rays would converge are illuminated only by the feebly luminous sodium flame, and accordingly appear dark by contrast with the other portions of the spectrum which receive light from the powerful flame behind.

By replacing one of the flames, G or H (fig. 420), by a ray of solar light reflected from a heliostat, Kirchhoff ascertained by direct comparison that the bright lines which characterise iron correspond to dark lines in the solar spectrum. He also found the same to be the case with sodium, magnesium, calcium, nickel, and some other metals.

From these observations we may draw important conclusions with to the constitution of the sun. Since the solar spectrum has dark here sodium, iron, etc., give bright ones (No. 11. Plate I.), it is prob- at around the solid, or more probably liquid, body of the sun, which out the light, there exists a vaporous envelope which, like the sodium n the experiment described above, absorbs certain rays, namely, hich the envelope itself emits. Hence those parts of the spectrum but for this absorption, would have been illuminated by these lar rays, appear feebly luminous in comparison with the other parts, hey are illuminated only by the light emitted by the envelope, and the solar nucleus; and we are at the same time led to conclude this vapour there exists the metals sodium, iron, etc.

gins and Miller have applied spectrum analysis to the investigation heavenly bodies. The spectra of the moon and planets, whose reflected from the sun, give the same lines as those of the sun. s proves an exception to this, and is probably still in a self- us condition. The spectra of the fixed stars contain, however, ines differing from the solar lines, and from one another. Four t types of spectra are distinguished by Père Secchi. The first ces the white stars and includes the well-known Sirius and α Lyræ. spectra (No. 12, Plate I.) usually contain a number of very fine nd always contain four broad dark lines, which coincide with the lines of hydrogen. Out of 346 stars 164 were found to belong to oup. The second group embraces those having spectra intersected nerous fine lines like those of our sun. About 140 stars, among Pollux, Capella, ϕ Aquilæ, belong to this group. The third group ces the red and orange stars, such as α Orionis, β Pegasi; the of these (Nos. 13, 14, Plate I.) are divided into eight or ten parallel nar clusters of dark and bright bands increasing in intensity to the Group four is made up of small red stars with spectra, and is con- d of three bright zones increasing in intensity towards the violet. ld thus appear that these fixed stars, while differing from one r in the matter of which they are composed, are constructed on the eneral plan as our sun. Huggins has observed a striking difference spectra of the nebulæ; where they can at all be observed, they are to consist generally of bright lines, like the spectra of the ignited instead of like the spectra of the sun and stars consisting of a ground intersected by dark lines. It is hence probable that the are masses of glowing gas, and do not consist, like the sun and of a photosphere surrounded by a gaseous atmosphere.

of the most interesting triumphs of spectrum analysis has been the ery of the true nature of the *protuberances*, which appear during a eclipse as mountains or cloud-shaped luminous objects varying in nd surrounding the moon's disc.

ing the eclipse of 1868 it had been ascertained by Jannsen that nitted certain bright lines coinciding with those of hydrogen. They however, been fully understood only since Lockyer and Jannsen discovered a method of investigating them at any time. The prin- f this method is as follows:—When a line of light admitted through a slit is decomposed by a prism, the length of this spectrum may be increased by passing it through two or more prisms : as the quantity of light is the same, it is clear that the intensity of the spectrum will be diminished. This is the case with the ordinary sources of light, such as the sun ; if the light be homogeneous, it will be merely deviated, and not reduced in intensity by dispersion. And if the source of light emit lights of both kinds, the image of the slit of light of a definite refrangibility which the mixture may contain will stand out by their superior intensity on the weaker ground of the continuous spectrum. This is the case with the spectrum of the protuberances. Viewed through an ordinary spectroscope, the light they emit is overshadowed by that of the sun ; but by using prisms of great dispersive power the sun's light becomes weakened, and the spectrum of the protuberances may be obscured. Lockyer's researches leave no doubt that they are ignited gas masses, principally of hydrogen. By altering the position of the slit a series of sections of the prominences are obtained by collating which the form of the prominence may be inferred. They are thus found to enclose the sun usually to a depth of about 5,000 miles, but sometimes in enormous local accumulations, which reach the height of 70,000 miles. Lockyer has not merely examined these phenomena right on the edge of the sun ; but he has been able to observe them on the disc itself. He has shown that some of these protuberances are the results of sudden outbursts or storms, which move with the enormous velocity of 120 miles in a second. For a fuller account of this branch of Physics, which is incompatible with the limits of this work, the reader is referred to Roscoe's 'Lectures on Spectrum Analysis,' and to the same writer's articles in Watts's 'Dictionary of Chemistry,' or to Schellen's 'Spectrum Analysis,' translated by Lassell.

532. **Uses of the spectroscope.**—When a liquid placed in a glass tube or in a suitable glass cell is interposed between a source of light and the slit of the spectroscope, on looking through the telescope, the spectrum observed will in many cases be found to be traversed by dark bands. No. 10, Plate I, represents the appearance of the spectrum when a solution of *chlorophylle*, the green colouring matter of plants, is thus interposed. Both in the red, the yellow and the violet parts dark bands are formed, and the blue gives way to a reddish shimmer. If instead of chlorophylle arterial blood greatly diluted be used, the red of the spectrum appears brighter, but green and violet are nearly extinguished. As these bands thus differ in different liquids as regards position, breadth, and intensity, in many cases they afford the most suitable means of identifying bodies. Sorby and Browning have devised a combination of the microscope and spectroscope, called the *microspectroscope*, which renders it possible to examine even very minute traces of substances.

This application of the spectroscope has been very useful in investigating substances which have special importance in physiology and pathology ; thus, in examining normal and diseased blood, in detecting albumen in urine, and in ascertaining the rate at which certain substances ito the various fluids of the system. The characteristic absorption which certain liquids, such as wine, beer, etc., present in their state, compared with those yielded by adulterated substances, es a delicate and certain means of detecting the latter.

Fluorescence.—Professor Stokes has made the remarkable dis- that under certain circumstances the rays of light are capable of oing a change of refrangibility. The discovery originated in the f a phenomenon observed by Sir J. Herschel, that certain solutions ooked at by transmitted light appear colourless, but when viewed cted light present a bluish appearance. Stokes has found that this y, which he calls *fluorescence*, is characteristic of a large class of

phenomenon is best seen when a solution of sulphate of quinine, ed in a trough with parallel sides, is placed in different positions solar spectrum. No change is observed in the upper part of the m, but from about the middle of the lines G and H (coloured Plate) e distance beyond the extreme range of the violet, rays of a beau- y-blue colour are seen to proceed. These invisible ultra-violet rays come visible when the spectrum is allowed to fall on paper im- ted with a solution of *æsculine* (a substance extracted from horse it), an alcoholic solution of stramonium, or a plate of canary glass is coloured by means of uranium). This change arises from a tion in the refrangibility of those rays outside the violet, which are rily too refrangible to affect the eye.

s appears to absorb many of these more refrangible rays, which is case nearly to the same extent with quartz. When prisms and formed of plates of quartz are used, a spectrum may be obtained outside the line H, is double the length of the visible spectrum. spectrum thus made visible dark lines may be seen like those in linary spectrum.

phenomena may be observed without the use of a prism. When rture in a dark room is closed by means of a piece of blue glass, e light is allowed to fall upon a piece of canary glass, it instantly s self-luminous from the emission of the altered rays.

ost cases it is the violet and ultra-violet rays which undergo an on of refrangibility, but the phenomenon is not confined to them. ction of madder in alum gives yellow and violet light from about e D to beyond the violet; an alcoholic solution of chlorophylle ed light from the line B to the limit of the spectrum. In these the yellow, the green, and the blue rays experience diminution angibility; the change never produces more highly refrangible

electric light gives a very remarkable spectrum. With quartz tus Stokes obtained a spectrum six or eight times as long as the ry one. Several flames of no great illuminating power emit very ar light. Characters traced on paper with solution of stramonium, are almost invisible in daylight, appear instantaneously when illuminated by the flame of burning sulphur. Robinson has found that the light of the aurora is peculiarly rich in rays of high refrangibility.

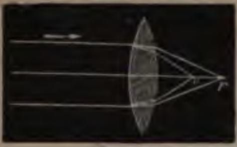

Fig. 421.

534. **Chromatic aberration.**—The various lenses hitherto described (509) possess the inconvenience that, when at a certain distance from the eye, they give images with coloured edges. This defect, which is most observable in condensing lenses, is due to the unequal refrangibility of the simple colours (520), and is called *chromatic aberration.*

For, as a lens may be composed to a series of prisms with infinitely small faces, and united at their bases, it not only refracts light, but also decomposes it like a prism. On account of this dispersion, therefore, lenses have really a distinct focus for each colour. In condensing lenses, for example, the red rays, which are the least refrangible, form their focus at a point, *r*, on the axis of the lens (fig. 421), while the violet rays, which are most refrangible, coincide in the nearer point, *v*. The foci of the orange, yellow, green, blue, and indigo are between these points. The chromatic aberration is more perceptible in proportion as the lenses are more convex, and as the point at which the rays are incident is further from the axis; for then the deviation, and therefore the dispersion are increased.

57 534. **Achromatism.**—By combining prisms which have different refracting angles (501), and are formed of substances of unequal dispersive powers (519), white light may be refracted without being dispersed. The same result is attained by combining lenses of different substances, the curvatures of which are suitably combined. The images of objects viewed through such lenses do not appear coloured, and they are accordingly called *achromatic* lenses; *achromatism* being the term applied to the phenomenon of the refraction of light without decomposition.

By observing the phenomenon of the dispersion of colours in prisms of water, of oil, of turpentine, and of crown glass, Newton was led to suppose that dispersion was proportional to refraction. He concluded that there could be no refraction without dispersion, and, therefore, that achromatism was impossible. Almost half a century elapsed before this was found to be incorrect. Hall, an English philosopher, in 1733, was the first to construct achromatic lenses, but he did not publish his discovery. It is to Dollond, an optician in London, that we owe the greatest improvement which has been made in optical instruments. He showed in 1757 that by combining two lenses, one a double convex crown glass lens, the other a concavo-convex lens of flint glass (fig. 422), a lens is obtained which is virtually achromatic.

To explain this result, let two prisms, BFC and CDF, be joined and turned in a contrary direction, as shown in fig. 423. Let us suppose, in the first case, that both prisms are of the same material, but that the refracting angle of the second, CDF, is less than the refracting angle of the first; the two prisms will produce the same effect as a single prism, BAF; that is to say, that white light which traverses it will not only be ted, but also decomposed. If, on the contrary, the first prism BCF f crown glass, and the other of flint glass, the dispersion might be yed without destroying the refraction. For as flint glass is more sive than crown, and as the dispersion produced by a prism dimi- with its refracting angle (519), it follows that by suitably lessening fracting angle of the flint glass prism CFD, as compared with the ing angle of the crown glass prism BCF, the dispersive power of prisms may be equalised; and as, from their position, the dispersion place in a contrary direction, it is neutralised; that is, the emergent O are parallel, and therefore give white light. Nevertheless, the f the angles BCF and CFD, which is suitable for the parallelism red rays and violet rays, is not so for the intermediate rays, and, uently, only two of the rays of the spectrum can be exactly com- and the achromatism is not quite perfect. To obtain perfect

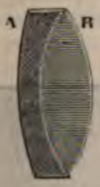

Fig. 422.

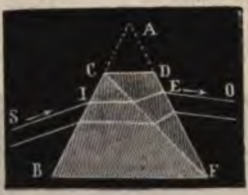

Fig. 423.

atism, several prisms would be necessary, of unequally dispersive als, and the angles of which were suitably combined.

refraction is not destroyed at the same time as the dispersion: uld only happen if the refracting power of a body varied in the atio as its dispersive power, which is not the case. Consequently, ergent ray EO is not exactly parallel to the incident ray, and there fraction without appreciable decomposition.

romatic lenses are made of two lenses of unequally dispersive ma- : one, A, of flint glass, is a diverging concavo-convex (fig. 422); er, B, of crown glass, is double convex, and one of its faces may coincide with the concave face of the first. As with prisms, lenses would be necessary to obtain perfect achromatism; but for instruments two are sufficient, their curvature being such as to e the blue and orange rays.

CHAPTER V.

OPTICAL INSTRUMENTS.

The different kinds of optical instruments.—By the term *instrument* is meant any combination of lenses, or of lenses and s. Optical instruments may be divided into three classes, accord- the ends they are intended to answer, viz. :—i. *Microscopes*, which are designed to obtain a magnitude image of any object whose real dime sions are too small to admit of its being seen distinctly by the naked ey ii. *Telescopes*, by which very distant objects, whether celestial or terre trial, may be observed. iii. *Instruments* designed to project on a scre a magnified or diminished image of any object which can thereby either depicted or rendered visible to a crowd of spectators; such as t *camera lucida*, the *camera obscura*, *photographic apparatus*, the *mag lantern*, the *solar microscope*, the *photo-electric microscope*, etc. The t former classes yield virtual images; the last, with the exception of t *camera lucida*, yield real images.

MICROSCOPES.

537. **The simple microscope.**—The *simple microscope* or *magnifyi glass* is merely a convex lens of short focal length, by means of which look at objects placed between the lens and its principal focus. Let A (fig. 424) be the object to be observed placed between the lens and

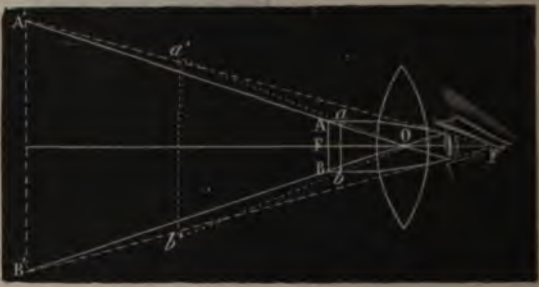

Fig. 424.

principal focus, F. Draw the secondary axes AO and BO, and also fr A and B rays parallel to the axis of the lens FO. Now these rays, passing out of the lens, tend to pass through the second principal fo F', consequently they are divergent with reference to the secondary a and therefore, when produced, will cut those axes in A' and B' resp tively. These points are the virtual foci of A and B respectively. T lens therefore produces at A'B' an erect and magnified virtual imag the object AB.

The position and magnitude of this image depend on the distance the object from the focus. Thus, if AB is moved to *ab* nearer the le the secondary axes will contain a greater angle, and the image wil formed at *a'b'*, and will be much smaller, and nearer the eye. On other hand, if the object is moved farther from the lens the angle betw the secondary axes is diminished, and their intersection with the p longation of the refracted rays taking place beyond A'B', the imag formed farther from the lens, and is larger.

In a simple microscope both chromatic aberration and spher ration increase with the degree of magnification. We have already that the former can be corrected by using achromatic lenses , and the latter by using diaphragms, which allow the passage of rays only as are nearly parallel to the axis, the spherical aberration iese rays being nearly insensible. Spherical aberration may be

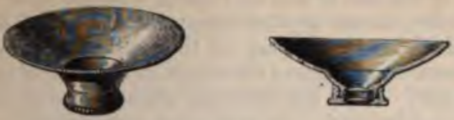

Fig. 425.

further corrected by using two plano-convex lenses, instead of very convergent lens. When this is done, the plane face of each is turned towards the object (fig. 425). Although each lens is convex than the simple lens which they replace, yet their joint ifying power is as great, and with a less amount of spherical aber- , since the first lens draws towards the axis the rays which fall on second lens. This combination nses is known as *Wollaston's* *et.*

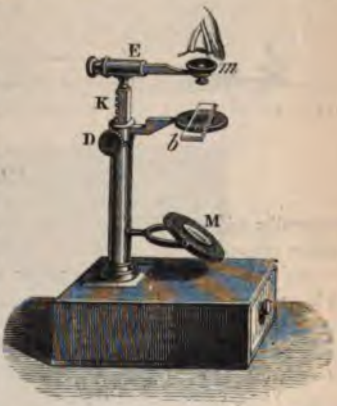

Fig. 426.

ere are many forms of the simple scope. One of the best is that sented in fig. 426. On a hori- l support, E, which can be raised lowered by a rack and pinion, is a black *eyepiece*, *m*, in the e of which is fitted a small con- ens. Below this is the *stage*, is fixed, and on which the object aced between glass plates. In to illuminate the object power- diffused light is reflected from a ve glass mirror, M, so that the ted rays fall upon the object. sing this microscope, the eye ced very near the lens, which is lowered or raised until the position nd at which the object appears in its greatest distinctness.

. **Conditions of distinctness of the images.**— In order that s looked at through a microscope should be seen with distinctness nust have a strong light thrown upon them, but this is by no means h. It is necessary that the image be formed at a determinate ce from the eye. In fact, there is for each person a *distance of distinct vision*, a distance, that is to say, at which an object must be l from an observer's eye, in order to be seen with greatest dis- ess. This distance is different for different observers, but ordi- is between 10 and 12 inches. It is, therefore, at this distance the eye that the image ought to be formed. Moreover, this is why each observer has *to focus* the instrument, that is, to adapt the microscope to his own distance of most distinct vision. This is effected by slightly varying the distance from the lens to the object, for we have seen above that a slight displacement of the object causes a great displacement of the image. With a common magnifying glass, such as is held in the hand, the adjustment is effected by merely moving it nearer to or farther from the object. In the microscope the adjustment is effected by means of a rack and pinion, which in the case of the instrument shown in fig. 426 moves the instrument, but moves the object in the case of the instrument depicted in fig. 431. What has been said about *focussing* the microscope applies equally to telescopes. In the latter instruments the eyepiece is generally adjusted with respect to the image formed in the focus of the object glass.

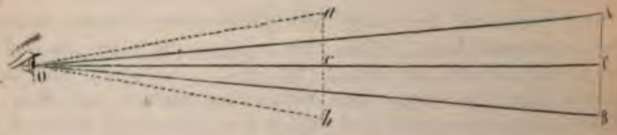

Fig. 427.

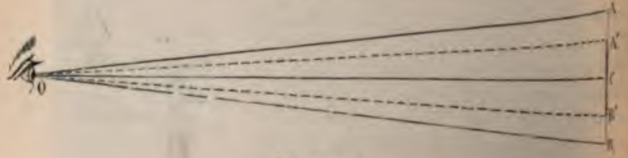

Fig. 428.

539. **Apparent magnitude of an object.**—The apparent magnitude or apparent diameter of a body is the angle it subtends at the eye of the observer. Thus, if AB is the object, and O the observer's eye (figs. 427, 428), the apparent magnitude of the object is the angle AOB contained by two visual rays drawn from the centre of the pupil to the extremities of the object.

In the case of objects seen through optical instruments, the angles which they subtend are so small that the arcs which measure the angles do not differ sensibly from their tangents. The ratio of two such angles is therefore the same as that of their tangents. Hence we deduce the two following principles :—

I. *When the same object is seen at unequal distances, the apparent diameter varies inversely as the distance from the observer's eye.*

II. *In the case of two objects seen at the same distance, the ratio of the apparent diameters is the same as that of their absolute magnitudes.*

These principles may be proved as follows :—i. In fig. 427, let AB be the object in its first position, and *ab* the same object in its sec position. For the sake of distinctness these are represented in s positions that the line OC passes at right angles through their mid

: and *c* respectively. It is, however, sufficient that *ab* and AB pe the bases of isosceles triangles having a common vertex at O. y what has been said above, AB is virtually an arc of a circle ed with centre O and radius OC; likewise *ab* is virtually an arc of whose centre is O and radius O*c*. Therefore,

$$\text{AOB} : a\text{O}b = \frac{\text{AB}}{\text{OC}} : \frac{ab}{\text{O}c} = \frac{1}{\text{OC}} : \frac{1}{\text{O}c}.$$

re, AOB varies inversely as OC.

et AB and A′B′ be two objects placed at the same perpendicular e, OC, from the eye, O, of the observer (fig. 428). Then they are y arcs of a circle whose centre is O and radius OC. Therefore,

$$\text{AOB} : \text{A}'\text{OB}' = \frac{\text{AB}}{\text{OC}} : \frac{\text{A}'\text{B}'}{\text{OC}} = \text{AB} : \text{A}'\text{B}',$$

rtion which expresses the second principle.

Measure of magnification.—In the simple microscope, the mea- the magnification produced is the ratio of the apparent diameter image to that of the object, both being at the distance of most dis- ision.* The same rule holds good for other microscopes. It is, r, important to obtain an expression for the magnification depend- data that are of easier determination.

g. 429 let AB be the object, and A′B′ its image formed at the dis- f most distinct vision. Let *a′b′* be the projection of AB on A′B′.

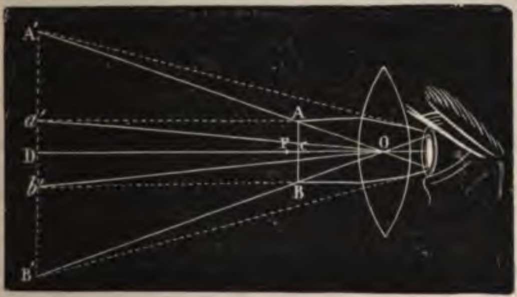

Fig. 429.

since the eye is very near the glass, the magnification equals or $\frac{\text{A}'\text{B}'}{a'b'}$, that is, $\frac{\text{A}'\text{B}'}{\text{AB}}$. But since the triangles A′OB′ and AOB ilar, A′B′ : AB = DO : CO. Now DO is the distance of most vision, and CO is very nearly equal to FO, the focal length of the Therefore the magnification equals the ratio of the distance of

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mpler and more general definition may be stated thus:—Let *a* be the angular de of the object as seen by the naked eye, β the angular magnitude of the vhether real or virtual, actually present to the eye, then the magnification is This rule applies to telescopes.

most distinct vision to the focal length of the lens. Hence we conclude that the magnification is greater :—1st, as the focal length of the lens is smaller, in other words, as the lens is more convergent; 2ndly, as the observer's distance of most distinct vision is greater.

By changing the lens the magnification can be increased, but only within certain limits if we wish to obtain a distinct image. By means of a simple microscope distinct magnification may be obtained up to 120 diameters.

The magnification we have now considered is *linear* magnification. *Superficial* magnification equals the square of the *linear* magnification; for instance, the former will be 1,600 when the latter is 40.

541. **Compound microscope.**—The compound microscope in its simplest form consists of two condensing lenses: one, with a short focus, is called the *object glass* or *objective*, because it is turned towards the object; the other is less condensing, and is called the *eyepiece* or *power*, because it is close to the observer's eye.

Fig 430 represents the path of the luminous rays, and the formation of the image in the simplest form of a compound microscope. An object, AB, being placed very near the principal focus of the object glass, M, but a little farther from the glass, a real image, *ab*, inverted and somewhat magnified, is formed on the other side of the object glass (510). Now the distance of the two lenses, M and N, is such that the position of the image, *ab*, is between the eyepiece N, and its focus, F. From this it follows that for the eye at E, looking at the image through the eyepiece this glass produces the same effect as a simple microscope, and instead of this image, *ab*, another image, *a′b′*, is seen, which is virtual, and still more magnified. This second image, although erect as regards the first, is inverted in reference to the object. It may thus be said, that the compound microscope is nothing more than a simple microscope applied not to the object, but to its image already magnified by the first lens.

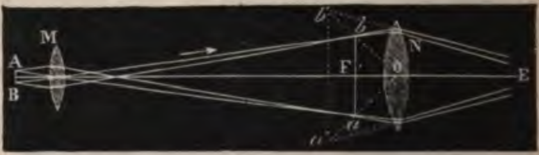


Fig. 430.

542. **Amici's compound microscope.**—The principle of the compound microscope has been already (541) explained; the principal accessories to the instrument remain to be described.

Fig. 431 represents a perspective view, and fig. 432 a section of a compound microscope. The body of the microscope consists of a series of brass tubes, DD′, H, and I, in the former of these is fitted the eyepiec and in the lower part of the latter the object glass, *o*. The tube I mov with gentle friction in the tube, DD′, which in turn can also be moved a larger tube fixed in the ring E. This latter is fixed to a piece, H by means of a very fine screw, worked by the milled head T, can ved up and down an inner rod, *c*, not represented in the figure. hole body of the microscope is raised and lowered with the piece o that it can be placed near or far from the object to be examined. ver, the rod, *c*, and all the other pieces of the apparatus rest on ontal axis, A, with which they turn under so much friction as to fixed in any position in which they may be placed.

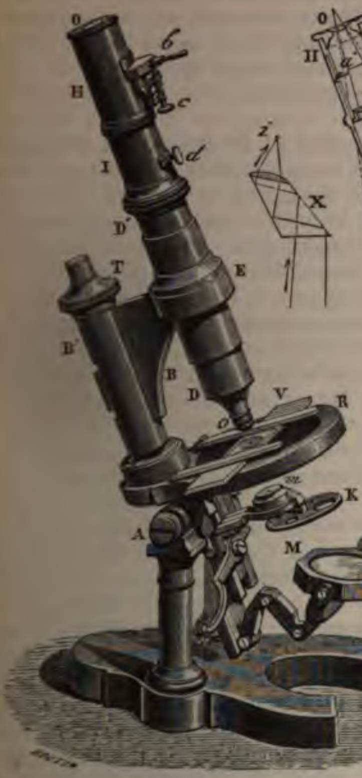


Fig. 431.

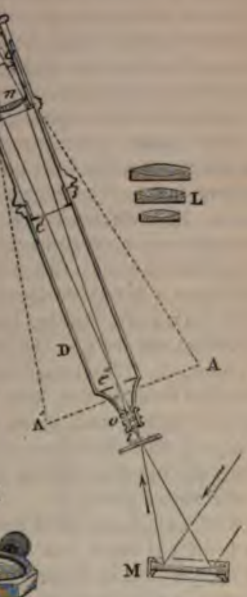


Fig 432.

e objects to be observed are placed between two glass plates, V, on *ge*, R. This is perforated in the centre so that light can be reflected it by a concave reflecting glass mirror, M. The mirror is mounted articulated support, so that it can be placed in any position what- so as to reflect to the object either the diffused light of the atmo- re or that from a candle or lamp. Between the reflector and the stage *liaphragm* or *stop*, K, perforated by four holes of different sizes, anyone hich can be placed over the perforation in the stage, and thus the light falling on the object may be regulated; the light can moreover be regulated by raising by a lever, *n*, the diaphragm, K, which is moveable in a slide. Above the diaphragm is a piece, *m*, to which can be attached either a very small stop, so that only very little light can reach the object, or a condensing lens, which illuminates it strongly, or an oblique prism, represented at X. The rays from the reflector undergo two total reflections in this prism, and emerge by a lenticular face that concentrates them on the object, but in an oblique direction which in some microscopic observations is an advantage. Objects are generally so transparent that they can be lighted from below; but where, owing to their opacity, this is not possible, they are lighted from above by means of a condensing lens mounted on a jointed support, and so placed that they receive the diffused light of the atmosphere.

Fig. 432 shows the arrangement of the lenses and the path of the rays in the microscope. At *o* is the object glass, consisting of three small condensing lenses, represented on a larger scale at L, on the right of the figure. The effects of these lenses being added to each other they act like a single very powerful condensing lens. The object being placed at *i*, a very little beyond the principal focus of the system, the emerging rays fall upon a fourth condensing lens, *n*, the use of which will be seen presently (543, 544). Having become more convergent, owing to their passage through the lens, *n*, the rays form at *aa'* a real and amplified image of the object, *i*. This image is between a fifth condensing lens, O, and the principal focus of this lens. Hence, on looking through this, it acts as a magnifier (514), and gives at AA, a virtual and highly magnified image of *aa'*, and therefore of the object. The two glasses, *n* and O, constitute the eyepiece in the same manner as the three glasses, *o*, constitute the object glass.

The first image, *aa*, must not merely be formed between the glass, O, and its principal focus, but at such a distance from this glass that the second image, AA, is formed at the observer's distance of distinct vision. This result is obtained in moving, by the hand the body, DH, of the microscope in the larger tube fixed to the ring, E, until a tolerably distinct image is obtained; then turning the milled head, T, in one direction or the other, the piece, BB, and with it the whole microscope, are moved until the image, AA, attains its greatest distinctness, which is the case when the image, *aa*, is formed at the distance of distinct vision: a distance which can always be ultimately obtained, for as the object glass approaches or recedes from the object, the image, *aa*, recedes from or approaches the eyepiece, and at the same time the image, AA.

This operation is called the *focussing*. In the microscope, where the distance from the object glass to the eyepiece is constant, it is effected by altering their distance from the object. In telescopes, where the objects are inaccessible, the object is effected by varying the distance of the eyepiece and the object glass.

The microscope possesses numerous eyepieces and object glasses, means of which a great variety of magnifying power is obtained. A sm magnifying power is also obtained by removing on or two of the lenses of the object glass.

The above contains the essential features of the microscope; it is made in a great variety of forms, which differ mainly in the construction of the stand, the arrangement of the lenses, and in the illumination. For descriptions of these, the student is referred to special works on the microscope.

543. **Achromatism of the microscope. Campani's eyepiece.**—When a compound microscope consists of two single lenses, as in fig. 421, not only is the spherical aberration uncorrected, but also the chromatic aberration, the latter defect causing the images to be surrounded by fringes of the prismatic colours, these fringes being larger as the magnification is greater. It is with a view to correcting these aberrations that the object glass (see fig. 420) is composed of three achromatic lenses, and the eyepiece of two lenses, *n* and *m*, for the first of these, *n*, would be enough to produce colour unless the magnifying power were low.

The effect of this eyepiece in correcting the colour may be explained as follows :—It will be borne in mind that with respect to red rays the focal length of a lens is *greater* than the focal length of the same lens with reference to the violet rays.

In fact, if equation (4), we write $R' = \infty$, we obtain $f = \frac{R}{n-1}$, which gives the focal length of a plano-convex lens whose refractive index is *n*. Now,

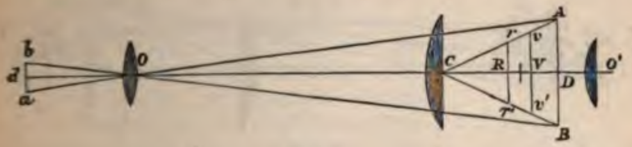


Fig. 433.

in flint glass, and for the red ray, $n - 1$ equals 0·63, and for the violet ray $- 1$ equals 0·67.

Let *ab* be the object, O the object glass which is corrected for colour. Consequently, a pencil of rays falling from *a* on O would converge to a focus, A, without any separation of colours, but falling on the *fieldglass* C, the red rays would converge to *r*, the violet rays to *v*, and intermediate colours, to intermediate points. In like manner the rays from *b*, after passing through the fieldglass, would converge to *r'*, *v'*, and intermediate points. So that on the whole there would be formed a succession of coloured images of *ab*, viz. a red image at *rr'*, a violet image at *vv'*, and between them images of intermediate colours. Let *d* be the point of the object which is situated on the axis. The rays from *d* will converge to , V, and intermediate points. Now suppose the *eyeglass* O' to be placed in such a manner that R is the principal focus of O' for the red rays, then will V be its principal focus for the violet rays. Consequently, the red rays, after emerging from O', will be parallel to the axis, and so will the violet rays emerging from V, and so of any other colour. Consequently the colours of *d*, which are separated by C, are again combined by O The same is very nearly true of *r* and *v*, and of *r′* and *v′*. Hence combination of the lenses C and O′ corrects the chromatic aberration tha would be produced by the use of a single eyeglass. Moreover, b drawing the rays towards the axis, it diminishes the spherical aberration and, as we shall see in the next article, enlarges the field of view.

In all eyepieces consisting of two lenses the lens to which the eye i applied is called the *eye lens*, the one towards the object glass is calle the *field lens*. The eyepiece above described was invented by Huyghen who was not, however, aware of its property of achromatism. He designed it for use with the telescope. It was applied to the microscope b Campani. The relation between the focal lengths of the lenses is a follows :—The focal length of the fieldglass is three times that of the ey lens, and the distance between their centres is half the sum of the foca length. It easily follows from this that the image of the point *d* would but for the interposition of the field lens, be formed at D, which is s situated that CD is three times DO′, then the mean of the coloure images will be formed midway between C and O′.

544. **Field of view.**—By the field of view of an optical instrument i meant all those points which are visible through the eyepiece. Th advantage obtained by the use of an eyepiece in enlarging the field o view will be readily understood by an inspection of the accompanyin figure. As before, O is the object glass, C the field lens, O′ the eye lens and E the eye placed on the axis of the instrument. Let *a* be a point o the object ; if we suppose the field lens removed, the pencil of rays from a would be brought to a focus at A, and none of them would fall on the eye lens O′, nor pass into the eye E. Consequently, *a* is beyond the field of view. But when the field glass C is interposed, the pencil of rays is brought to a focus at A′, and emerges from O′ into the eye. Consequently, *a* is now within the field of view. It is in this manner that the substitution of an eyepiece for a single eye lens enlarges the field of view.

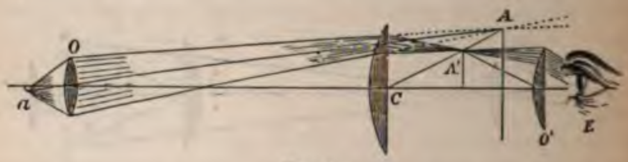


Fig. 434.

545. **Magnifying power. Micrometer.**—The magnifying power of any optical instrument is the ratio of the magnitude of the image to the magnitude of the object. The magnifying power in a compound microscope is the product of the respective magnifying powers of the object glass and of the eyepiece ; that is, if the first of these magnifies 20 times and the other 10, the total magnifying power is 200. The magnifying power depends on the greater or less convexity of the object glass and o

piece, as well as on the distance between these two glasses, to-
with the distance of the object from the object glass. A magni-
ower of 1,500 and even upwards has been obtained; but the image
es in sharpness what it gains in extent. To obtain precise and
minated images, the magnifying power ought not to exceed 500
diameters, which gives a superficial enlargement 250,000 to
times that of the object.

magnifying power is determined experimentally by means of the
ter; this is a small glass plate, on which, by means of a diamond,
of lines is drawn at a distance from each other of $\frac{1}{10}$ or $\frac{1}{100}$ of a
ter. The micrometer is placed in front of the object glass, and
stead of viewing directly the rays emerging from the eyepiece, O,
received on a piece of glass, A (fig. 435), inclined at an angle of
l the eye is placed above so as to see the image of the micrometer
hich is formed by reflection on a screen, E, on which is a scale
into millimeters. By counting the number of divisions of this
rresponding to a certain number of lines of the image, the mag-
power may be deduced. Thus, if the image occupies a space of 45
ters on the scale, and contains 15 lines of the micrometer, the dis-
etween each of which shall be assumed at
limeter, the absolute magnitude of the
will be $\frac{15}{100}$ millimeter; and as the image
s a space of 45 millimeters, the magnifi-
will be the quotient of 45 by $\frac{15}{100}$ or 300.
e in this experiment ought to be at
distance from the screen, E, that the
is distinctly visible: this distance varies
fferent observers, but is usually 10 to 12
The magnifying power of the micro-
an also be determined by means of the
lucida.

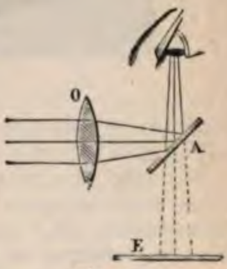


Fig. 435.

n once the magnifying power is known,
olute magnitude of objects placed before the microscope is easily
d. For, as the magnifying power is nothing more than the
t of the size of the image by the size of the object, it follows that
of the image divided by the magnifying power gives the size
object; it is in this manner that the diameter of all microscopic
is determined.

TELESCOPES.

Astronomical telescope.—The *astronomical telescope* is used for
ng the heavenly bodies; like the microscope, it consists of a con-
eyepiece and object glass. The object glass, M (fig. 436), forms
the eyepiece, N, and its principal focus an inverted image of the
y body, and this eyepiece, which acts as a magnifying glass, then
virtual and highly magnified image, *a'b'*, of the image *ab*. The
mical telescope appears, therefore, analogous to the microscope;

but the two instruments differ in this respect : that in the microscope, object being very near the objective, the image is formed much bey the principal focus, and is greatly magnified, so that both the object g and the eyepiece magnify; while in the astronomical telescope,

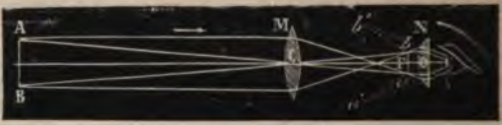


Fig. 436.

heavenly body being at a great distance, the incident rays are paral and the image formed in the principal focus of the object glass is m smaller than the object. There is, therefore, no magnification except the eyepiece, and this ought, therefore, to be of very short focal length.

Fig. 437 shows an astronomical telescope mounted on its stand. Ab

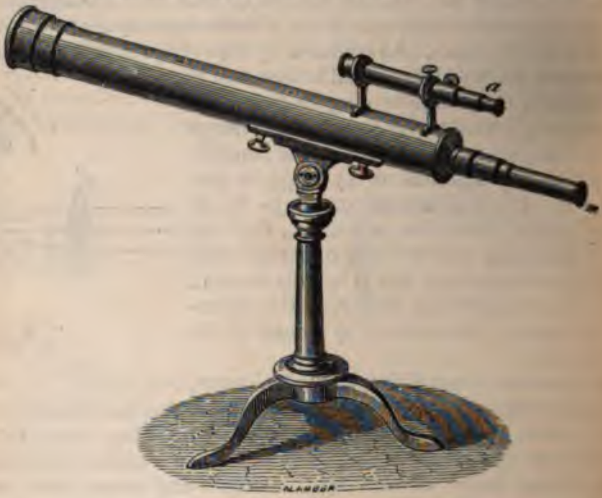


Fig. 437.

it there is a small telescope, which is called the *finder*. Telescopes wi a large magnifying power are not convenient for finding a star, as th have but a small field of view : the position of the star is, accordin first sought by the finder, which has a much larger field of view, that takes in a far greater extent of the heavens : it is then viewed by mea of the telescope.

The magnification (note, art. 526) equals $\frac{ACB}{a'Ob'}$ (fig. 436); that is, it equ $\frac{bCO}{bOC}$, and therefore is approximately equal to $\frac{CF}{OF}$, F being the focus of t ect glass, M, and being supposed very nearly to coincide with the focus the eyepiece, N; it may, therefore, be concluded that the magnifying wer is greater in proportion as the object glass is less convergent, and eyepiece more so.

When the telescope is used to make an accurate observation of the rs, for example, their zenith distance or their passage r the meridian, a *cross wire* is added. This consists of very fine metallic wires or spider threads stretched oss a circular aperture in a small metal plate (fig. 438). e wires ought to be placed in the position where the erted image is produced by the object glass, and the nt where the wires cross ought to be on the optical axis the telescope, which thus becomes the *line of sight* or *collimation*.

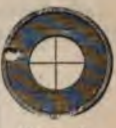


Fig. 438.

47. **Terrestrial telescope.**—The *terrestrial telescope* differs from the ronomical telescope in producing images in their right positions. is is effected by means of two condensing glasses, P and Q (fig. 439), ced between the object glass, M, and the eyepiece, R. The object ng supposed to be at AB, at a greater distance than can be shown in drawing, an inverted and much smaller image is formed at *ba* on the er side of the object glass. But the second lens, P, is at such a ance that its principal focus coincides with the image *ab*; from which llows that the luminous rays which pass through *b*, for example, after ersing the lens, P, take a direction parallel to the secondary axis, *b*O). Similarly the rays passing by *a* take a direction parallel to the , *a*O. After crossing on H, these various rays traverse a third lens, whose principal focus coincides with the point H. The pencil B*b*H verges towards *b′*, on a secondary axis, O′*b*, parallel to its direction; pencil A*a*H converging in the same manner at *a′*, an erect image of object, AB, is produced at *a′b′*. This image is viewed, as in the ronomical telescope, through a condensing eyepiece, R, so placed that cts as a magnifying glass, that is, its distance from the image, *a′b′*, is than the principal focal distance; hence, there is formed, at *a″b″*, a ual image of *a′b′*, erect, and much magnified. The lenses P and Q, ch only serve to rectify the position of the image, are fixed in a brass , at a constant distance, which is equal to the sum of their principal l distances. The object glass, M, moves in a tube, and can be moved r from the lens P, so that the image, *ab*, is always formed in the focus e lens whatever be the distance of the object. The distance of the , R, may also be varied so that the image, *a″b″*, may be formed at the ance of distinct vision.

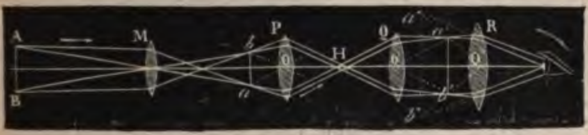


Fig. 439.

This instrument may also be used as an astronomical telescope by us a different eyepiece; this must have a much greater magnifying po than in the former cases.

In the terrestrial telescope the magnifying power is the same as in astronomical telescope, provided always that the correcting glasses, P Q, have the same convexity.

548. **Galilean telescope.**—The *Galilean telescope* is the simples all telescopes, for it only consists of two lenses, namely, an object gl

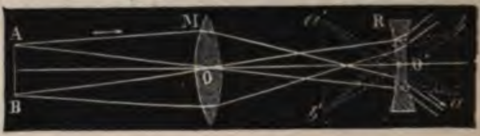


Fig. 440.

M, and a diverging or double concave eyepiece, R (fig. 440), and it g at once an erect image. *Opera glasses* are constructed on this princ

If the object be represented by the right line AB, a real but inve and smaller image would be formed at *ba*; but in traversing the eyepi R, the rays emitted from the points A and B are refracted, and div from the secondary axes, *b*O′ and *a*O′, which correspond to the poin and *a* of the image. Hence, these rays produced backward meet t axes in *a*′ and *b*′: the eye which receives them sees accordingly an e and magnified image in *a*′*b*′, which appears nearer because it is seen u an angle, *a*′O′*b*′, greater than the angle, AOB, under which the obje seen.

The magnifying power is equal to the ratio of the angle *a*′O′*b*′ to angle AOB, and is usually from 2 to 4.

The distance of the eyepiece R from the image *ab* is pretty nearly e to the principal focal distance of this eyepiece; it follows, therefore, the distance between the two lenses is the difference between thei spective focal distances; hence, Galileo's telescope is very short and p able. It has the advantage of showing objects in their right posit and, further, as it has only two lenses, it absorbs very little light: in sequence, however, of the divergence of the emergent rays, it has on small field of view, and in using it the eye must be placed very near eyepiece. The eyepiece can be moved to or from the object glass, so the image *a*′*b*′ is always formed at the distance of distinct vision.

The opera glass is usually double, so as to produce an image in eye, by which greater brightness is attained.

The time at which telescopes were invented is not known. Some tribute their invention to Roger Bacon in the 13th century; other J. B. Porta at the end of the 16th; others again to a Dutchman, Jac Metius, who, in 1609, accidentally found that by combining two gla one concave and the other convex, distant objects appeared nearer much larger.

Galileo's was the first telescope directed towards the heavens. B

Galileo discovered the mountains of the moon, Jupiter's satellites, spots on the sun.

Reflecting telescopes.—The telescopes previously described are *ing* or *dioptric* telescopes. It is, however, only in recent times that een possible to construct achromatic lenses of large size ; before concave metallic mirror was used instead of the object glass. pes of this kind are called *reflecting* or *catoptric telescopes*. The al forms are those devised by Gregory, Newton, Herschel, and rain.

The Gregorian telescope.—Figure 441 is a representation of y's telescope ; it is mounted on a stand, about which it is move-

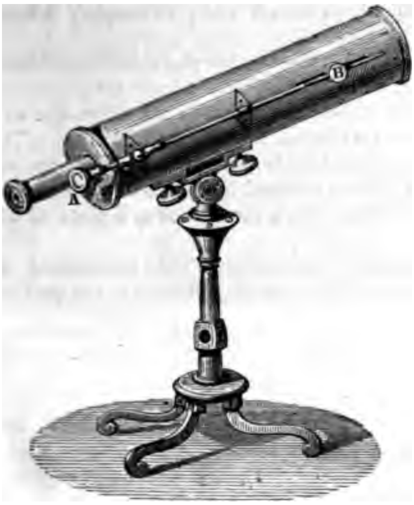


Fig. 441.

nd can be inclined at any angle. This mode of mounting is al ; it may be equatorially mounted. Fig. 442 gives a longitudinal It consists of a long brass tube closed at one end by a concave

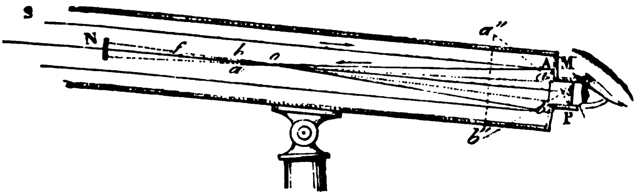


Fig. 442.

c mirror, M, which is perforated in the centre by a round aperture h which rays reach the eye. There is a second concave metal N, near the end of the tube ; it is somewhat larger than the central aperture in the large mirror, and its radius of curvature is much smaller than that of the large mirror. The axes of both mirrors coincide with the axis of the tube. As the centre of curvature of the large mirror is at O, and its focus at *ab*, rays, such as SA, emitted from a heavenly body, are reflected from the mirror M, and form at *ab* an inverted and very small image of the heavenly body. The distance of the mirrors and their curvatures is so arranged that the position of this image is between the centre, *o*, and the focus, *f*, of the small mirror; hence the rays, after being reflected a second time from the mirror N, form at *a′b′* a magnified and inverted image of *ab*, and therefore in the true position of the heavenly body. This image is viewed through an eyepiece, P, which may either be single or compound, its object being to magnify it again so that it is seen at *a″b″*.

As the objects viewed are not always at the same distance, the focus of the large mirror, and therefore that of the small one, vary in position. And as the distance of distinct vision is not the same with all eyes, the image *a″b″* ought to be formed at different distances. The required adjustments may be obtained by bringing the small mirror nearer or farther from the larger one; this is effected by means of a milled head, A (fig. 441), which turns a rod, and this by a screw moves a piece to which the mirror is fixed.

551. **The Newtonian telescope.**—This instrument does not differ much from that of Gregory; the large mirror is not perforated, and there is a small plane mirror inclined at an angle of 45° towards an eyepiece placed in the side of the telescope. The difficulty of constructing metallic mirrors has caused telescopes of Gregorian and Newtonian construction to fall into disuse. Of late, however, the process of silvering glass mirrors has been carried to a high state of perfection, and M. Foucault has applied these mirrors to Newtonian telescopes with great success. His first mirror was only four inches in diameter, but he has successively constructed mirrors of 8, 12, and 13 inches, and at the time of his death had completed one of 32 inches diameter.

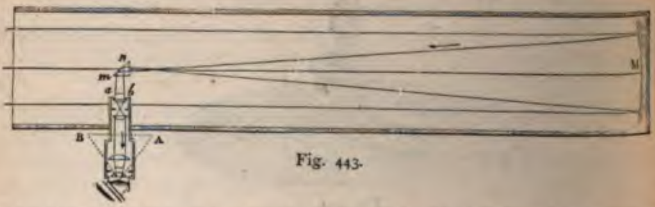


Fig. 443.

Fig. 444 represents a Newtonian telescope mounted on an equatorial stand, and fig. 443 gives a horizontal section of it. This section shows how the luminous rays reflected from the parabolic mirror, M, meet a smal rectangular prism, *mn*, which replaces the inclined plane mirror used i the old form of Newtonian telescope. After undergoing a total reflectio from *mn*, the rays form at *ab* a very small image of the heavenly body This image is viewed through an eyepiece with four lenses placed on th of the telescope, and magnifying from 50 to 800 times, according to size of the silvered mirror.

n reflectors the mirror acts as object glass, but there is, of course, no matic aberration.

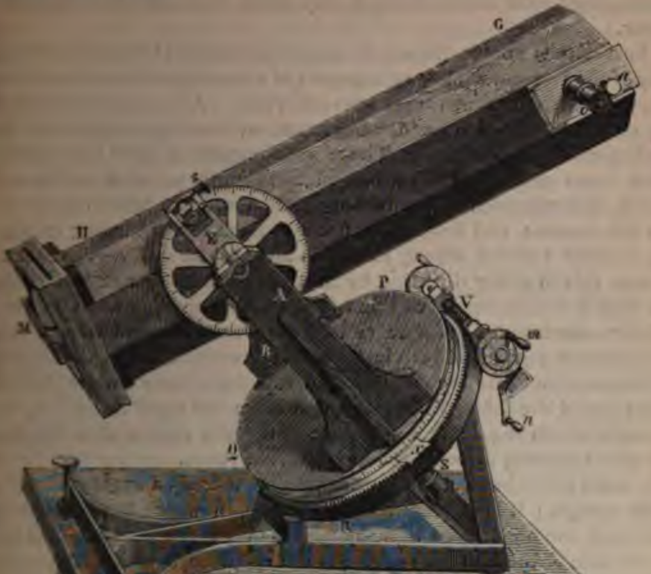


Fig. 444.

he spherical aberration is corrected by the form given to the reflector, ch is paraboloid, but slightly modified by trial to suit the eyepiece d to the telescope.

he mirror once polished is immersed in a silvering liquid, which con- essentially of ammoniacal solution of nitrate of silver, to which some cing agent is added. When a polished glass surface is immersed in solution, silver is deposited on the surface in the form of a brilliant metallic layer, which adheres so firmly that it can be polished with rouge in the usual manner.

These new telescopes with glass mirrors have the advantage over the old ones that they give purer images, they weigh less, and are much shorter, their focal distance being only about six times the diameter of the mirror.

These details known, the whole apparatus remains to be described. The body of the telescope (fig. 444) consists of an octagonal wooden tube. The end, G, is open; the mirror is at the other end. At a certain distance from this end two axles are fixed, which rest on bearings supported by two wooden uprights, A and B. These are themselves fixed to a table, PQ, which turns on a fixed plate, RS, placed exactly parallel to the equator. On the circumference of the turning table there is a brass circle, divided into 360 degrees, and beneath it, but also fixed to the turning table, there is a circular toothed wheel, in which an endless screw, V, works. By moving this in either direction by means of the handle *m*, the table PQ, and with it the telescope, can be turned. A vernier, *x*, fixed to the plate RS, gives the fractions of a degree. On the axis of the motion of the telescope there is a graduated circle, O, which serves to measure the *declination* of the star, that is, its angular distance from the equator; while the degrees traced round the table, RS, serve to measure the *right ascension*, that is, the angle which the declination circle of the star makes with the declination circle passing through the first point of Aries.

In order to fix the telescope in declination, there is a brass plate, E, fixed to the upright; it is provided with a clamp, in which the limb O works, and which can be screwed tight by means of a screw with a milled head, *r*. On the side of the apparatus there is the eyepiece, *o*, which is mounted on a sliding copper plate, on which there is also the small prism *mn*, represented in section in fig. 443. To bring the image to the right place, this plate may be moved by means of a rack and a milled head, *a*. The handle, *n*, serves to *clamp* or *unclamp* the screw, V. The drawing was one taken from a telescope, the mirror of which is only 6½ inches in diameter, and which gives a magnifying power of 150 to 200.

552. **The Herschelian telescope.**—Sir W. Herschel's telescope, which, until recently, was the most celebrated instrument of modern times, was

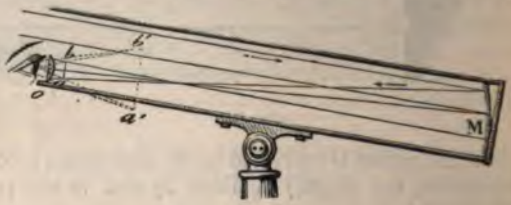


Fig. 445.

constructed on a method differing from those described. The mirror was so inclined that the image of the star was formed at *ab* on the side of the telescope near the eyepiece, *o*; hence it is termed the *front view* telescope.

As the rays in this telescope only undergo a single reflection, the loss of ght is less than in either of the preceding cases, and the image is there ore brighter. The magnifying power is the quotient of the principal foca- istance of the mirror by the focal distance of the eyepiece.

Herschel's great telescope was constructed in 1789; it was 40 feet in ngth, the great mirror was 50 inches in diameter. The quantity of ght obtained by this instrument was so great as to enable its inventor o use magnifying powers far higher than anything which had hitherto een attempted.

Herschel's telescope has been exceeded by one constructed by the late Earl of Rosse. This magnificent instrument has a focal length of 53 eet, the diameter of the speculum being six feet. It is at present used as Newtonian telescope, but it can also be arranged as a front view elescope.

INSTRUMENTS FOR FORMING PICTURES OF OBJECTS.

553. **Camera obscura.**—The *camera obscura* (dark chamber) is, as its ame implies, a closed space impervious to light. There is, however, a mall aperture by which luminous rays enter, as shown in fig. 446. The ay, proceeding from external objects, and entering by this aperture, forms n the opposite side an image of the object in its natural colours, but of educed dimensions, and in an inverted position.

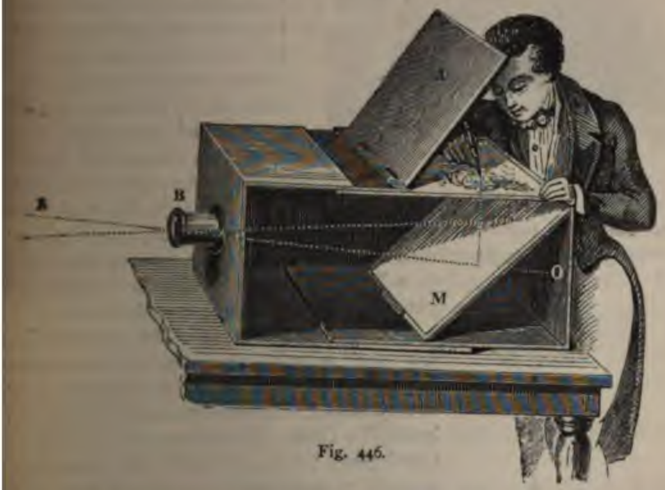


Fig. 446.

Porta, a Neapolitan physician, the inventor of this instrument, found that fixing a double convex lens in the aperture, and placing a white screen the focus, the image was much brighter, and more definite.

Fig. 446 represents a camera obscura, such as is used for drawing. It nsists of a rectangular wooden box, formed of two parts which slide in and out. The luminous rays, R, pass into the box by a lens, B, and form an image on the opposite side, O, which is at the focal distance of the lens. But the rays are reflected from a glass mirror, M, inclined at an angle of 45°, and form an image on a ground glass plate, N. When a piece of tracing paper is placed on this screen, a drawing of the image is easily made. A wooden door, A, cuts off extraneous light.

The box is formed of two parts, sliding one within the other, like the joints of a telescope, so that, by elongating it more or less, the reflected image may be made to fall exactly on the screen, N, at whatever distance the object may be situated.

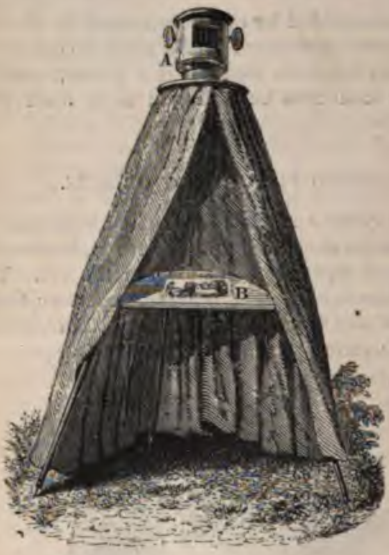


Fig. 447.

Fig. 447 shows another kind of camera obscura, which is occasionally erected in summer houses. In a brass case, A, there is a triangular prism, P (fig. 448), which acts both as condensing lens and as mirror. One of its faces is plane, but the others have such curvatures that the combined refractions on entering and emerging from the prism produce the effect of a meniscus lens. Hence rays from an object, AB, after passing into the prism and undergoing total reflection from the face *cd*, form at *ab* a real image of AB.

In fig. 447, the small table B corresponds to the focus of the prism in the case A, and an image forms on a piece of paper placed on the table. The whole is surrounded by a black curtain, so that the observer can place himself in complete darkness.

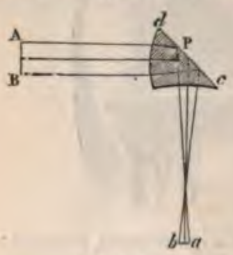


Fig. 448.

554. **Camera lucida.**—The *camera lucida* is a small instrument depending on internal reflection, and serves for taking an outline of any object. It was invented by Dr. Wollaston, in 1804. It consists of a small four-sided glass prism, of which fig. 449 gives a section perpendicular to the edges. A is a right angle, and C an angle of 135°; the other angles, B and D, are 67½°. The prism rests on a stand, on which it can be raised or lowered, and turned more or less about an axis parallel to the prismatic edges. When the face, AB, is turned towards the object, the rays from the

object fall nearly perpendicular on this face, pass into the prism without any appreciable refraction, and are totally reflected from BC; for as the line ab is perpendicular to BC, and nL to AB, the angle anL will equal the angle B—that is, it will contain $67\frac{1}{2}^\circ$, and this being greater than the critical angle of glass (498), the ray Ln will undergo total reflection. The rays are again totally reflected from o, and emerge near the summit, D, in a direction almost perpendicular to the face DA, so that the eye which receives the rays sees at L′ an image of the object L. If the outlines of the image are traced with a pencil, a very correct design is obtained; but unfortunately there is a great difficulty in seeing both the image and the point of the pencil, for the rays from the object give an image which is farther from the eye than the pencil. This is corrected by placing between the eye and prism a lens, I, which gives to the rays from the pencil and those from the object the same divergence. In this case, however, it is necessary to place the eye very near the edge of the prism, so that the aperture of the pupil is divided into two parts, one of which sees the image and the other the pencil.

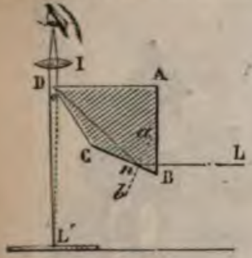


Fig. 449.

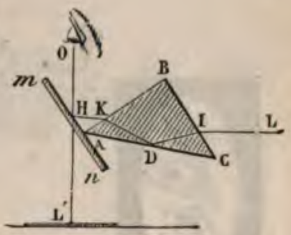


Fig. 450.

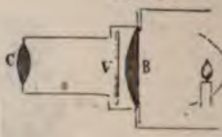
Amici's camera lucida, represented in fig. 450, is preferable to that of Wollaston, inasmuch as it allows the eye to change its position to a considerable extent, without ceasing to see the image and the pencil at the same time. It consists of a rectangular glass prism, ABC, having one of its perpendicular faces turned towards the object to be depicted, while the other is at right angles to an inclined plate of glass, mn. The rays, LI, proceeding from the object, and entering the prism, are totally reflected from its base at D, and emerge in the direction KH. They are then partially reflected from the glass plate mn at H, and form a vertical image of the object, L, which is seen by the eye in the direction OL′. The eye at the same time sees through the glass the point of a pencil applied to the paper, and thus the outline of the picture may be traced with great exactness.

555. **Magic lantern.**—This is an apparatus by which a magnified image of small objects may be projected on a white screen in a dark room. It consists of a tin plate box, in which there is a lamp placed in the focus of a concave mirror, A (fig. 452). The reflected rays fall upon a condensing lens, B (fig. 451), which concentrates them on the figure painted on a glass plate, V. There is a double convex lens, C, at a dis-

tance from V of rather more than its focal distance, and, consequently, a real and very much magnified image of the figure on the glass is produced on the screen (514).

Dissolving views are obtained by arranging two magic lanterns, which are quite alike, with different pictures, in such a manner that both pictures are produced on exactly the same part of a screen. The object glasses of both lanterns are closed by screens, which are so arranged that according as one is raised the other is lowered, and *vice versâ*. In this way one picture is gradually seen to change into the other.

Fig. 451.



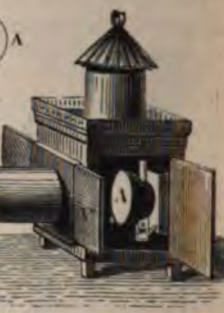


Fig. 452.

The magnifying power of the magic lantern is obtained by dividing the distance of the lens C from the image by its distance from the object. If the image is 100 or 1,000 times farther from the lens than the object, the image will be 100 or 1,000 times as large. Hence a lens with a very short focus can produce a very large image, provided the screen is sufficiently large.

556. **Solar microscope.**—The solar microscope is in reality a magic lantern illuminated by the solar rays; it serves to produce highly magnified images of very small objects. It is worked in a dark room; fig. 453 represents it fitted in the shutter of a room, and fig. 454 gives the internal details.

The solar rays fall on a plane mirror, M, placed outside the room, and are reflected towards a condensing lens, *l*, and from thence to a second lens, *o* (fig. 454), by which they are concentrated at its focus. The object to be magnified is at this point; it is placed between two glass plates, which, by means of a spring, *n*, are kept in a firm position between two metal plates, *m*. The object thus strongly illuminated is very near the focus of a system of three condensing lenses, *x*, which forms upon a screen at a suitable distance an inverted and greatly magnified image, *ab*. The distance of the lenses, *o* and *x*, from the object is regulated by means of screws, C and D.

As the direction of the solar light is continually varying, the position of the mirror outside the shutter must also be changed, so that the reflection is always in the direction of the axis of the microscope. The most exact apparatus for this purpose is the heliostate (492); but as this nstrument is very expensive, the object is usually attained by inclining he mirror to a greater or less extent by means of an endless screw B

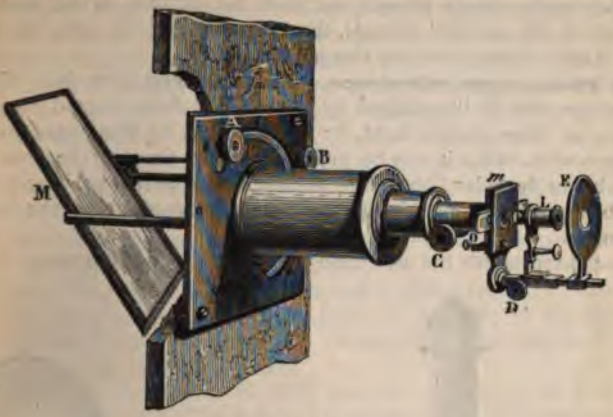


Fig. 453.

nd at the same time turning the mirror itself round the lens, *l*, by a knob , which moves in a fixed slide.

The solar microscope labours under the objection of concentrating reat heat on the object, which soon alters it. This is partially obviated y interposing a layer of a saturated solution of alum, which, being a

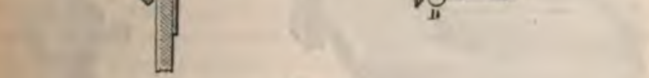


Fig. 454.

owerfully athermanous substance, cuts off a considerable portion of the eat.

The magnifying power of the solar microscope may be deduced experientally by substituting for the object a glass plate marked with lines at distance of $\frac{1}{10}$ or $\frac{1}{100}$ of a millimeter. Knowing the distance of these nes on the image, the magnifying power may be calculated. The same method is used with the photoelectric light. According to the magi ing power which it is desired to obtain, the objective x is formed of two, or three lenses, which are all achromatic.

The solar microscope furnishes the means of exhibiting to a l audience many curious phenomena, such, for instance, as the circula of blood in the smaller animals, the crystallisation of salts, the oc rence of animalculæ in water, vinegar, etc. etc.

557. **Photoelectric microscope.**—This is nothing more than the s microscope, but is illuminated by the electric light instead of by sun's rays. The electric light, by its intensity, its steadiness, and readiness with which it can be procured at any time of the day, is preferable to the solar light. The photoelectric microscope alone wi described here: the electric light will be considered under the hea Galvanism.

Fig. 455 represents the arrangement devised by M. Duboscq. A s

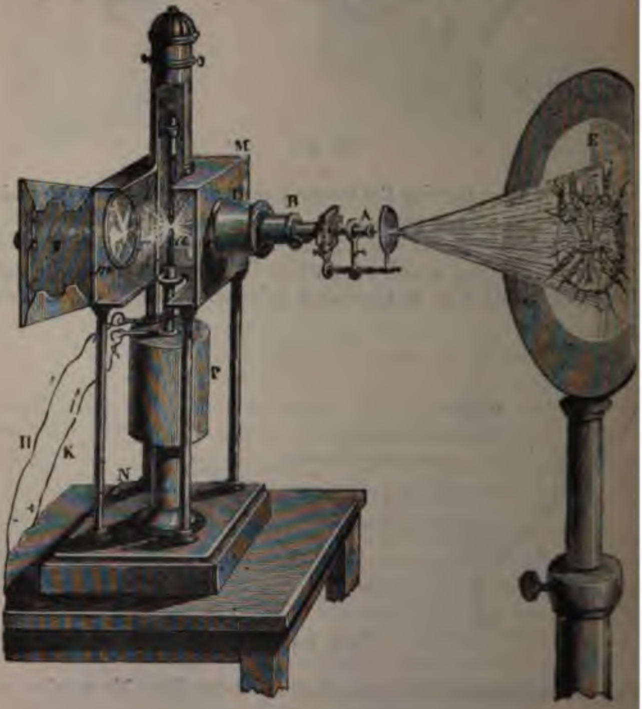


Fig. 455.

microscope, ABD, identical with that already described, is fixed on outside of a brass box. In the interior are two charcoal points w do not quite touch, the space between them being exactly on the of the lenses. The electricity of one end of a powerful battery reaches the charcoal, *a*, by means of a copper wire, K: while the electricity from the opposite end of the battery reaches *c* by a second copper wire, H.

During the passage of the electricity, a luminous arc is formed between the two ends of the carbons, which gives a most brilliant light, and powerfully illuminates the microscope. This is effected by placing at D in the inside of the tube a condensing lens, whose principal focus corresponds to the space between the two charcoals. In this manner the luminous rays, which enter the tubes, D and B, are parallel to their axis, and the same effects are produced as with the ordinary solar microscope; a magnified image of the object placed between two plates of glass is produced on the screen.

In continuing the experiment, the two carbons become consumed, and to an unequal extent, *a* more quickly than *c*. Hence, their distance increasing, the light becomes weaker and is ultimately extinguished. In speaking afterwards of this electric light, the working of the apparatus, P, which keeps these charcoals at a constant distance, and thus ensures a constant light, will be explained.

The part of the apparatus, MN, may be considered as a universal *photogenic apparatus*. The microscope can be replaced by the head pieces of the phantasmagoria, the polyorama, the megascope, by polarising apparatus, etc., and in this manner is admirably adapted for exhibiting optical phenomena to a large auditory. Instead of the electric light, we may use with this apparatus the *oxy-hydrogen* or *Drummond's* light, which is obtained by heating a cylinder of lime in the flame produced by the combustion of a mixture of hydrogen and oxygen gases.

558. **Lighthouse lenses.**—Lenses of large dimensions are very difficult of construction; they further produce a considerable spherical aberration, and their thickness causes the loss of much light. In order to avoid these inconveniences, *échelon* lenses have been constructed. They consist of a plano-convex lens, C (figs. 456 and 457), surrounded by a series of annular and concentric segments, A, B, each of which has a plane face on the same side as the plane face of the central lens, while the faces on the other side have such a curvature that the foci of the different segments coincide in the same point. These rings form, together with the central lens, a single lens, a section of which is represented in fig. 457. The drawing was made from a lens of about 2 feet in diameter, the segments of which are formed of a single piece of glass; but with larger lenses, each segment is likewise formed of several pieces.

Behind the lens there is a support fixed by three rods, on which a body can be placed and submitted to the sun's rays. As the centre of the support coincides with the focus of the lens, the substances placed there are melted and volatilised by the high temperature produced. Gold, platinum, and quartz are rapidly melted. This experiment proves that heat is refracted in the same way as light: for the position of the calorific focus is identical with that of the luminous focus.

Formerly parabolic mirrors were used in sending the light of beacons and lighthouses to great distances, but they have been supplanted by the use of lenses of the above construction. In most cases, oil is used in a lamp of peculiar construction, which gives as much light as 20 moderators. The light is placed in the principal focus of the lens on the side of the plane face. The emergent rays consequently form a parallel beam (fig. 397), which loses intensity only by passing through the atmosphere, and can be seen at a distance of above 40 miles. In order that all points of the horizon may be successively illuminated, the lens is continually moved round the lamp by a clock-work motion, the rate of which varies with different lighthouses. Hence, in different parts, the light alternately appears and disappears after equal intervals of time. These alternations serve to distinguish lighthouses from an accidental fire or a star. By means too of the number of times the light disappears in a given time, and by the colour of the light, sailors are enabled to distinguish the lighthouses from one another, and hence to know their position.

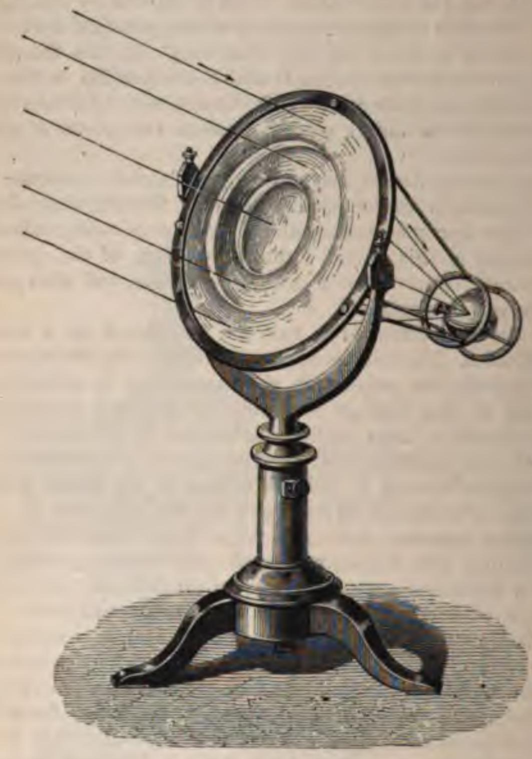


Fig. 456.

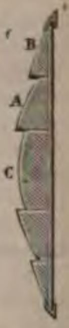


Fig. 457.

years the use of the electric light has been substituted for that
ps ; a description of the apparatus will be given in a subsequent

PHOTOGRAPHY.

aguerreotype.—*Photography* is the art of fixing the images of
ra obscura on substances *sensitive* to light. The various photo-
rocesses may be classed under three heads : photography on
otography on paper, and photography on glass.

ood was the first to suggest the use of chloride of silver in
image, and Davy, by means of the solar microscope, obtained
f small objects on paper impregnated with chloride of silver ;
ethod was known of preserving the images thus obtained, by
g the further action of light. Niepce, in 1814, obtained per-
mages of the camera by coating glass plates with a layer of
composed of bitumen dissolved in oil of lavender. This pro-
tedious and inefficient, and it was not until 1839 that the pro-
solved. In that year, Daguerre described a method of fixing
es of the camera, which, with the subsequent improvements
and Archer, has rendered the art of photography one of the
ellous discoveries ever made, either as to the beauty and per-
the results, or as to the celerity with which they are produced.

uerre's process, the *Daguerreotype*, the picture is produced on
copper coated with silver. This is first very carefully polished,
on on which much of the success of the subsequent operations
It is then rendered *sensitive* by exposing it to the action of
our, which forms a thin layer of iodide of silver on the surface.
is now fit to be exposed in the camera; it is sensitive enough
which require an exposure of ten minutes in the camera, but
ater rapidity is required, as for portraits, etc., it is further
the action of an *accelerator*, such as bromine or hypobromite
. All these operations must be performed in a room lighted
lle, or by the daylight admitted through yellow glass, which
l chemical rays. The plate is preserved from the action of
lacing it in a small wooden case provided with a slide on the
ide.

rd operation consists in exposing the sensitive plate to the
ight, placing it in that position in the camera where the image
d with greatest delicacy. For photographic purposes a camera
peculiar construction is used. The brass tube, A (fig. 458),
n achromatic condensing lens, which can be moved by means
ork motion, to which is fitted a milled head, D. At the op-
of the box is a ground-glass plate, E, which slides in a groove,
the case containing the plate also fits. The camera being
proper position before the object, the sliding part of the box
d until the image is produced on the glass with the utmost
this is the case when the glass slide is exactly in the focus.
djustment is made by means of the milled head, D.

The glass slide is then replaced by the case containing the sensitive plate; the slide which protects it is raised; and the plate exposed for a time, the duration of which varies in different cases, and can only be hit exactly by great practice. The plate is then removed to a dark room. No change is perceptible to the eye, but those parts on which the light has acted have acquired the property of condensing mercury: the plate is next placed in a box and exposed to the action of mercurial vapour at 60 or 70 degrees.

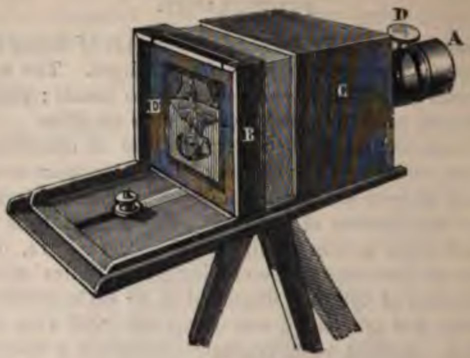


Fig. 458.

The mercury is deposited on the parts affected in the form of globules imperceptible to the naked eye. The shadows, or those parts on which the light has not acted, remain covered with the layer of iodide of silver. This is removed by treatment with hyposulphite of sodium, which dissolves iodide of silver without affecting the rest of the plate. The plate is next immersed in a solution of chloride of gold in hyposulphite of sodium, which dissolves the silver, while some gold combines with the mercury and silver of the parts attacked, and greatly increases the intensity of the lustre.

Hence the light parts of the image are those on which the mercury has been deposited, and the shaded those on which the metal has retained its reflecting lustre.

Fig. 459 represents a section of the camera and the object glass. At first it consisted of a double convex lens, but now double achromatic lenses, L L, are used as object glasses. They act more quickly than objectives with a single lens, have a shorter focus, and can be more easily focussed by moving the lens, L, by means of the rack and pinion, D.

560. **Photographs on paper.**—In Daguerre's process, which has just been described, the images are produced directly on metallic plates. With paper and glass, photographs of two kinds may be obtained: those in which an image is obtained with reversed tints, so that the lightest parts have become the darkest on paper, and *vice versâ*; and those in which the lights and shades are in their natural position. The former are called *negative* and the latter *positive* pictures.

A negative may be taken either on glass or on paper ; it serves to produce a positive picture.

Negatives on glass.—A glass plate of the proper size is carefully cleaned; collodion impregnated with iodide of potassium is then poured upon it, and the plate moved about till a layer of collodion of uniform thickness is obtained. The plate is then immersed for about a minute in a bath of nitrate of silver containing 30 grains of the salt in an ounce of water. This operation must be performed in a dark room. The plate is then removed, allowed to drain, and when somewhat dry, placed in the closed frame, and afterwards exposed in the camera, for a shorter time than in the case of a Daguerreotype. On removing the plate to a dark room, no change is visible, but on pouring over it a solution called the *developer*, an image gradually appears. The principal substances used for developing are protosulphate of iron and pyrogallic acid. The action of light on iodide of silver appears to produce some molecular change, in virtue of which the developers have the property of reducing to the metallic state those parts of the iodide of silver which have been most acted upon by the light. When the picture is sufficiently brought out, water is poured over the plate, in order to prevent the further action of the developer. The parts on which light has not acted are still covered with iodide of silver, which would be affected if the plate were now exposed to the light. It is, accordingly, washed with solution of hyposulphite of sodium, which dissolves the iodide of silver and leaves the image unaltered. The picture is then coated with a thin layer of spirit-varnish, to protect it from mechanical injury.

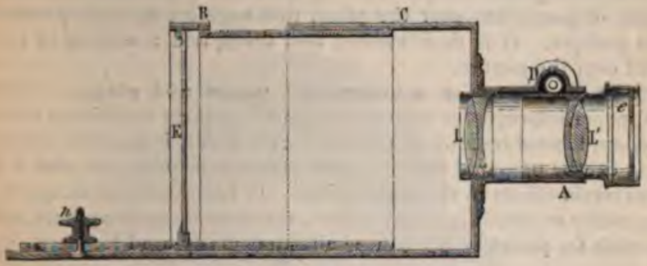


Fig. 459.

When once the negative is obtained, it may be used for printing an indefinite number of positive pictures. For this purpose, paper is impregnated with chloride of silver, by immersing it first in solution of nitrate of silver and then in one of chloride of sodium ; chloride of silver is thus formed on the paper by double decomposition. The negative is placed on a sheet of this paper in a copying frame, and exposed to the action of light for a certain time. The chloride of silver becomes acted upon—the light parts of the negative being most affected, and the dark parts least so. A copy is thus obtained, on which the lights of the negative are replaced by shades, and inversely. In order to fix the picture, it is washed in a solution of hyposulphite of sodium, which dissolves the unaltered chloride of silver. The picture is afterwards immersed in a bath of chloride of gold which gives it tone.

561. **Positives on glass.**—Very beautiful positives are obtained by preparing the plates as in the preceding cases; the exposure in the camera, however, is not nearly so long as for the negatives. The picture is then developed by pouring over it a solution of protosulphate of iron, which produces a negative image; and by afterwards pouring a solution of cyanide of potassium over the plate, this negative is rapidly converted into a positive. It is then washed and dried, and a coating of varnish poured over the picture.

562. **Photographs on albumenised paper and glass.**—In some cases, paper impregnated with a solution of albumen containing iodide of potassium is used instead of collodion, over which it has the advantage that it can be prepared for some time before it is used, and that it produces certain effects in the middle tints. It has the disadvantage of not being nearly so sensitive. It requires, therefore, longer exposure, and is unsuitable for portraits, but can be advantageously used for views.

CHAPTER VI.

THE EYE CONSIDERED AS AN OPTICAL INSTRUMENT.

563. **Structure of the human eye.**—The *eye* is the organ of *vision*—that is to say, of the phenomenon by virtue of which the light emitted or reflected from bodies excites in us the sensation which reveals their presence.

The eye is placed in a bony cavity called the orbit; it is maintained in its position by the muscles which serve to move it, by the optic nerve, the conjunctiva, and the eyelids. Its size is much the same in all persons: it is the varying aperture of the eyelids that makes the eye appear larger or smaller.

Fig. 460 represents a transverse section of the eye from back to front. The general shape is that of a spheroid, the curvature of which is greater in the anterior than in the posterior part. It is composed of the following parts: the *cornea*, the *sclerotica*, the *iris*, the *pupil*, the *aqueous humour*, the *crystalline*, the *vitreous body*, the *hyaloid membrane*, the *choroid*, the *retina*, and the *optic nerve*.

Cornea.—The cornea, *a*, is a transparent membrane situated in front of the ball of the eye. In shape it resembles a small watch glass, and it fits into the sclerotica, *i*; in fact, these membranes are so connected that some anatomists have considered them as one and the same, and have distinguished them by calling the cornea the *transparent*, and the sclerotica the *opaque* cornea.

Sclerotica.—The sclerotica, *i*, or *sclerotic* coat, is a membrane which, together with the cornea, envelopes all parts of the eye. In front there an almost circular aperture into which the cornea fits; a perforation behind gives passage to the optic nerve.

Iris.—The iris, *d*, is an annular, opaque diaphragm, placed between the cornea and the crystalline lens. It constitutes the coloured part of the eye, and is perforated by an aperture called the *pupil*, which in man is circular. In some animals, especially those belonging to the genus *felis*, it is narrow and elongated in a vertical direction; in the ruminants it is elongated in a transverse direction. It is a contractile membrane, and its diameter varies in the same individual between 0·12 and 0·28 of an inch; but these limits may be exceeded. The luminous rays pass into the eye through the pupil. The pupil enlarges in darkness, but contracts under the influence of a bright light. These alternations of contraction and enlargement take place with extreme rapidity; they are very frequent, and play an important part in the act of vision. The movements of the iris are involuntary.

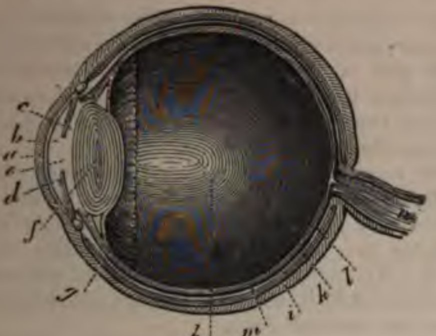


Fig. 460.

It appears from this description that the iris is a screen with a variable aperture, whose function is to regulate the quantity of light which penetrates into the eye; for the size of the pupil diminishes as the intensity of light increases. The iris serves also to correct the spherical aberration, as it prevents the marginal rays from passing through the edges of the crystalline lens. It thus plays the same part with reference to the eye that a diaphragm does in optical instruments (516).

Aqueous humour.—Between the posterior part of the cornea and the front of the crystalline there is a transparent liquid called the aqueous humour. The space, *e*, occupied by this humour is divided into two parts by the iris; the part *b*, between the cornea and the iris, is called the *anterior chamber*; the part *c*, which is between the iris and the crystalline, is the *posterior chamber*.

rystalline lens.—This is a double convex transparent body placed ediately behind the iris; the inner margin of which is in contact its anterior surface, though not attached to it. The lens is enclosed transparent membrane, called its *capsule*; it is less convex on its anterior than on its posterior surface, and is composed of almost concentric layers, which decrease in density and refracting power from the centre to the circumference.

To the anterior surface of the capsule, near its margin, is fixed a firm transparent membrane, which is attached behind to the front of the hyaloid membrane, and is known as the *suspensory ligament.* This ligament exerts a traction, all round, on the front surface of the lens, and renders it less convex than it would otherwise be, and its relaxation plays an important part in the adaptation of the eye for sight at different distances.

Vitreous body. Hyaloid membrane.—The vitreous body, or vitreous humour, is a transparent mass resembling the white of an egg, which occupies all the part of the ball of the eye, *h*, behind the crystalline. The vitreous humour is surrounded by the *hyaloid membrane*, *l*, which lines the posterior face of the crystalline capsule, and also the internal face of another membrane called the retina.

Retina. Optic nerve.—The retina, *m*, is a membrane which receives the impression of light, and transmits it to the brain by the intervention of a nerve, *n*, called the optic nerve, which, proceeding from the brain, penetrates into the eye, and extends over the retina in the form of a nervous network. The nerve fibres themselves are not sensitive to light, but are only stimulated by it indirectly through the intervention of certain structures called the *rods and cones.*

The only property of the retina and optic nerve is that of receiving and transmitting to the brain the impression of objects. These organs have been cut and pricked without causing any pain to the animals submitted to these experiments ; but there is reason to believe that irritation of the optic nerve causes the sensation of a flash of light.

Choroid.—The choroid, *k*, is a membrane between the retina and the sclerotica. It is completely vascular, and is covered on the internal face by a black substance which resembles the colouring matter of a negro's skin, and which absorbs all rays not intended to co-operate in producing vision.

The choroid elongates in front, and forms a series of convoluted folds, called *ciliary processes*, which penetrate between the iris and the crystalline capsule to which they adhere, forming round it a disk, resembling a radiated flower. By its vascular tissue, the choroid serves to carry the blood into the interior of the eye, and especially to the ciliary processes.

564. **Refractive indices of the transparent media of the eye.**—The refractive indices from air into the transparent parts of the eye have been determined by Brewster. His results are contained in the following table, compared with water as a standard ;—

Water	1·3358
Aqueous humour	1.3366
Vitreous humour	1·3394
Exterior coating of the crystalline	1·3767
Centre of the crystalline	1·3990
Mean refraction of the crystalline	1·3839

565. **Curvatures and dimensions of various parts of the human eye.**

Radius of curvature of the sclerotica	0·40 to 0·44 in.
„ „ cornea	0·28 to 0·32 „
„ „ anterior face of the crystalline	0·28 to 0·40 „
„ „ posterior face	0·20 to 0·24 „
Diameter of the iris	0·44 to 0·48 „
„ „ pupil	0·12 to 0·28 „
„ „ crystalline	0·40 „
Thickness of the crystalline	0·20 „
Distance from the pupil to the cornea	0·08 „
Length of the axis of the eye	0·88 to 0·96 „

The curvature of the cornea, according to M. Chossat, is that of an llipsoid of revolution round its major axis, and the curvature of the rystalline that of an ellipsoid of revolution round its minor axis.

566. **Path of rays in the eye.**—From what has been said as to the tructure of the eye, it may be compared to a camera obscura (553), of hich the pupil is the aperture, the crystalline is the condensing lens, nd the retina is the screen on which the image is formed. Hence, the ffect is the same as when the image of an object placed in front of a ouble convex lens is formed in its conjugate focus. Let AB (fig. 461)

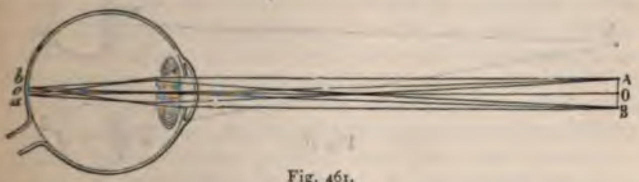


Fig. 461.

e an object placed before the eye, and let us consider the rays emitted om any point of the object A. Of all these rays those which are irected towards the pupil are the only ones which penetrate the eye, nd are operative in producing vision. These rays, on passing into the queous humour, experience a first refraction which brings them near the econdary axis, A*a*, drawn through the optic centre of the crystalline; hey then traverse the crystalline, which again refracts them like a double onvex lens, and having experienced a final refraction by the vitreous umour, they meet in a point, *a*, and form the image of the point A. he rays issuing from the point B form in like manner an image of it at he point *b*, so that a very small, real, and inverted image is formed xactly on the retina, provided the eye is in its normal condition.

567. **Inversion of images.**—In order to show that the images formed n the retina are really inverted, the eye of an albino or any animal ith pink eyes may be taken; this has the advantage that, as the horoid is destitute of pigment, light can traverse it without loss. This s then deprived at its posterior part of the cellular tissue surrounding it,

and fixed in a hole in the shutter of a dark room ; by means of a lens it may be seen that inverted images of external objects are depicted on the retina.

The inversion of images in the eye has greatly occupied both physicists and physiologists, and many theories have been proposed to explain how it is that we do not see inverted images of objects. The chief difficulty seems to have arisen from the conception of the mind or brain as something behind the eye looking into it and seeing the image upon the retina ; whereas really this image simply causes a stimulation of the optic nerve, which produces some molecular change in some part of the brain, and it is only of this change, and not of the image, as such, that we have any consciousness. The mind has thus no direct cognisance of the image upon the retina, nor of the relative positions of its parts, and sight being supplemented by touch in innumerable cases, it learns from the first to associate the sensations brought about by the stimulation of the retina (although due to an inverted image), with the correct position of the object as taught by touch.

568. **Optic axis, optic angle, visual angle.**—The *principal optic axis* of an eye is the axis of its figure ; that is to say, the straight line in reference to which it is symmetrical. In a well-shaped eye it is the straight line passing through the centre of the pupil and of the crystalline, such as the line O*o* (fig. 461). The lines A*a*, B*b*, which are almost rectilinear, are secondary axes. The eye sees objects most distinctly in the direction of the principal optic axis.

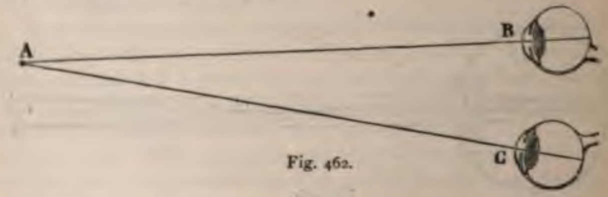


Fig. 462.

The *optic angle* is the angle BAC (fig. 462), formed between the principal optic axes of the two eyes when they are directed towards the same point. This angle is smaller in proportion as the objects are more distant.

The *visual angle* is the angle AOB (fig. 463), under which an object is seen ; that is to say, the angle formed by the secondary axes drawn from the optic centre of the crystalline to the opposite extremities of the object. For the same distance, this angle decreases with the magnitude of the

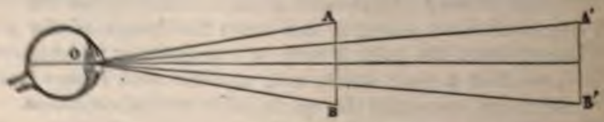


Fig. 463.

bject, and for the same object it decreases as the distance increases, as is he case when the object passes from AB to A′B′. It follows, therefore, hat objects appear smaller in proportion as they are more distant; for s the secondary axes, AO, BO, cross in the centre of the crystalline, the ize of the image projected on the retina depends on the size of the visual ngle, AOB.

569. **Estimation of the distance and size of objects.**—The estimation f distance and of size depends on numerous circumstances; these are— e visual angle. the optic angle, the comparison with objects whose size familiar to us, the diminution of the precision of the image by the interosition of a more or less vaporous medium.

When the size of an object is known, as the figure of a man, the height a tree or of a house, the distance is estimated by the magnitude of the sual angle under which it is seen. If its size is unknown, it is judged latively to that of objects which surround it.

A colonnade, an avenue of trees, the gas lights on the side of a road, pear to diminish in size in proportion as their distance increases, cause the visual angle decreases; but the habit of seeing the columns, ees, etc., in their proper height, leads our judgment to rectify the imession produced by vision. Similarly, although distant mountains e seen under a very small angle, and occupy but a small space in the ld of view, our familiarity with the effects of aërial perspective enables to form a correct idea of their real magnitude.

The optic angle is also an essential element in appreciating distance. is angle increasing or diminishing according as objects approach or ede, we move our eyes so as to make their optic axes converge towards object which we are looking at, and thus obtain an idea of its distance. evertheless, it is only by long custom that we can establish a relation ween our distance from the objects and the corresponding motion of the es. It is a curious fact that persons born blind, and whose sight has en restored by the operation for cataract, imagine at first that all objects at the same distance.

570. **Distance of distinct vision.**—The *distance of distinct vision* is, already stated, the distance at which objects must be placed so as to seen with the greatest distinctness. It varies in different individuals, d in the same individual it is often different in the two eyes. For small jects, such as print, it is from 10 to 12 inches in normal cases.

In order to obtain an approximate measurement of the least distance of tinct vision, two small parallel slits are made in a card at a distance of 3 of an inch. These apertures are held close before the eye, and when ne slit in another card is held very near these apertures, the slit is seen uble, because the rays of light which have traversed both apertures do intersect each other on the retina, but behind it. But, if the latter rd is gradually removed, the distance is ultimately reached at which both ages coincide and form one distinct image. Stampfer has constructed *optometer* on this principle.

Persons who see only at a very short distance are called *myoptic*, or *ort-sighted*, and those who see only at a long distance are *presbyoptic*, or *ng-sighted*.

571. **Accommodation.**—By this term is meant the changes which occ in the eye to fit it for seeing distinctly objects at different distances from

If the eye be supposed fixed and its parts immoveable, it is evident th there could only be one surface whose image would fall exactly upon th retina; the distance of this surface from the eye being dependent on th refractive indices of the media and the curvatures of the refracting su faces of the eye. The image of any point nearer the eye than this di tinctly seen surface would fall behind the retina; the image of any mo distant point would be formed in front of it: in each case the section of luminous cone would be perceived instead of the image of the point, an the latter would appear diffused and indistinct.

Experience, however, shows us that a normal eye can see distin images of objects at very different distances. We can, for example, see distant tree through a window, and also a scratch on the pane, though n both distinctly at the same moment; for when the eye is arranged to se one clearly, the image of the other does not fall accurately upon the retin An eye completely at rest seems adapted for seeing distant objects; th sense of effort is greater in a normal eye when a near object is looked a after a distant one, than in the reverse case; and in paralysis of th nerves governing the accommodating apparatus the eye is persistentl adapted for distant sight. There must, therefore, be some mechanism i the eye by which it can be voluntarily altered, so that the more divergen rays proceeding from near objects shall come to a focus upon the retin There are several conceivable methods by which this might be effected it is actually brought about by a drawing forwards of the crystalline len and a greater convexity of its anterior surface.

This is shown by the following experiment: if a candle be placed o one side of the eye of a person looking at a distant object, and his eye b observed from the other side, three distinct images of the flame will b seen; the first, virtual and erect, is reflected from the anterior surface o the cornea; the next, erect and less bright, is reflected from the anterio surface of the lens; the third, inverted and brilliant, is formed on the posterior surface of the lens. If now the person look at a near object, n change is observed in the first and third images, but the second imag becomes smaller and approaches the first; which shows that the anterio surface of the crystalline lens becomes more convex and approaches th cornea. In place of the candle, Helmholtz throws light through two hole in a screen upon the eye, and observes the distance on the eye betwee the two shining points, instead of the size of the flame of the candle.

This change in the lens is effected chiefly by means of a circula muscle (ciliary muscle), the contraction of which relaxes the suspensor ligament, and so allows the front surface of the lens to assume more o less of that greater convexity which it would normally exhibit were i not for the drag exercised upon it by the ligament. Certain other le important changes tending to make the lens more convex and to push forwards occur, which cannot, however, be explained without enterin into minute anatomical details. When the eye is accommodated for ne vision, the pupil contracts and so partially remedies the greater spheric aberration.

Binocular vision.—A single eye sees most distinctly any point ed on its optical axis, and less distinctly other points also, towards it is not directly looking, but which still are within its circle of

able to judge of the *direction* of any such point, but unable by o estimate its *distance*. Of the distance of an *object* it may indeed to judge by such criteria as loss of colour, indistinctness of outline, se in magnitude, etc.; but if the object is near, the single eye is fallible, even with these aids.

en the two eyes are directed upon a single point, we then gain the of judging of its distance as compared with that of any other and this we seem to gain by the sense of greater or less effort ed in causing the optical axes to converge upon the one point or the other. Now a solid object may be regarded as composed of which are at different distances from the eye. Hence, in looking h an object, the axes of the two eyes are rapidly and insensibly g their angle of convergence, and we as rapidly are gaining ence in the difference in distance of the various points of which ject is composed, or, in other words, an assurance of its solidity. kind of assurance is necessarily unattainable in monocular vision.

The principle of the stereoscope.—Let any solid object, such as ll box, be supposed to be held at some short distance before the two On whatever point of it they are fixed, they will see that point ost distinctly, and other points more or less clearly. But it is t that, as the two eyes see from different points of view, there will med in the right eye a picture of the object different from that

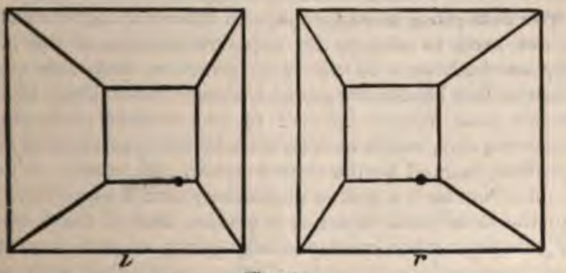


Fig. 464.

d in the left; and it is by the apparent union of these two dissimilar es that we see the object in relief. If, therefore, we delineate the , first as seen by the right eye, and then as seen by the left, and ards present these dissimilar pictures again to the eyes, taking care esent to each eye that picture which was drawn from its point w, there would seem to be no reason why we should not see a sentation of the object as we saw the object itself, in relief. Exent confirms the supposition. If the object held before the eyes were cated pyramid, *r* and *l*, fig. 464, would represent its principal lines, as seen by the right and left eyes respectively. If a card be held betwe the figures, and they are steadily looked at, *r* by the right eye, and simultaneously by the left, for a few seconds, there will be seen a sing picture having the unmistakable appearance of relief. Even without card interposed, the eye, by a little practice, may soon be taught so to con bine the two as to form this solid picture. Three pictures will in that ca be seen, the central being solid, and the two outside ones plane. Fig. 4 will explain this. Let *r* and *l* be any tw corresponding points, say the points marke by a large dot in the figures drawn above R and L the positions of the right and le eyes; then the right eye sees the point *r* i the direction R*o*, and the left eye the poin *l* in the direction L*o*, and accordingly, eac by itself judging only by the direction, they together see these two points as one, an imagine it to be situated at *o*. But the righ eye, though looking in the direction R*r*, als receives an image of *l* on another part of the retina, and the left eye in the same way an image of *r*, and thus three images are seen. A card, however, placed in the position marked by the dotted line will of course cut off the two side pictures. To assist the eye in combining such pairs of dissimilar pictures, both mirrors and lenses have been made use of, and the instruments in which either of these are adapted to this end are called *stereoscopes*.

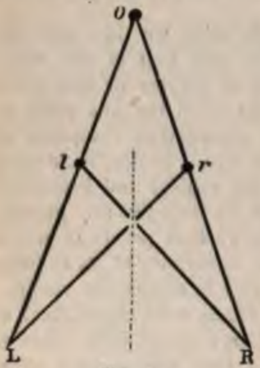


Fig. 465.

574. **The reflecting stereoscope.**—In the reflecting stereoscope plane mirrors are used to change the apparent position of the pictures, so that they are both seen in the same direction, and their combination by the eye is thus rendered easy and almost inevitable. If *ab*, *ab* (fig. 466) are two plane mirrors inclined to one another at an angle of 90°, the two arrows, *x*, *y*, would both be seen by the eyes situated at R and L in the position marked by the dotted arrow. If, instead of the arrows, we now substitute such a pair of dissimilar pictures as we have spoken of above, of the same solid object, it is evident that, if the margins of the pictures coincide, other corresponding points of the pictures will not. The eyes, however, almost without effort, soon bring such points into coincidence, and in so doing make them appear to recede or advance, as they are farther apart or nearer together than any two corresponding points (the right-hand corner, for instance) of the margins, when the pictures are placed side by side, as in the diagram, fig. 466. It will be plain, also, on considering the position for the arrows in fig. 466, that to adapt such pictures as those in fig. 464 to use in a reflecting stereoscope, one of them must be reversed, or drawn as it would be seen through the paper if held up to the light.

575. **The refracting stereoscope.**—Since the rays passing through a convex lens are bent always towards the thicker part of the lens, any

ient of such a lens may be readily adapted to change the apparent ion of any object seen through it. Thus, if (fig. 467) two segments

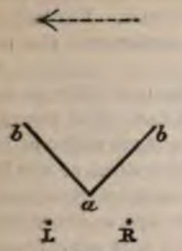
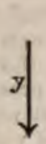


Fig. 466.



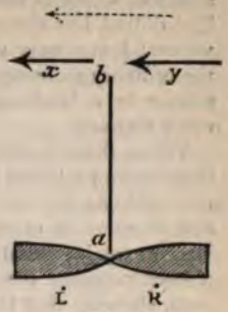


Fig. 467.

ut from a double convex lens, and placed with their edges together, rrows x, y, would both be seen in the position of the dotted arrow ie eyes at R and L.

we substitute for the arrows two dissimilar pictures of the same solid t, or the same landscape, we shall then, if a diaphragm, *ab*, be placed een the lenses to prevent the pictures being seen crosswise by the see but one picture, and that apparently in the centre, and magnified. efore, if the margins are brought by the power of the lenses to coin- other corresponding points will not be coincident until combined by most insensible effort of the eyes. Any pair of corresponding points h are farther apart than any other pair will then be seen farther back e picture, just as any point in the background of a landscape would und (if we came to compare two pictures of the landscape, one drawn ie right eye, and the other by the left) to be represented by two ts farther apart from one another than two others which represented nt in the foreground.

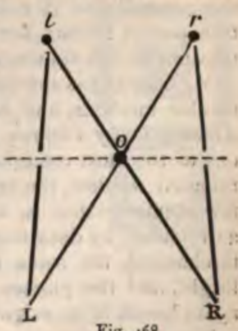


Fig. 468.

any one curious in such experiments, it will be instructive to notice there is also a second point on *this side* of paper, at which, if a person look steadily, liagrams in fig. 468 will combine, and form a different stereoscopic picture. Instead solid pyramid, a hollow pyramidal box will be seen. The point may easily be found by riment. Here again two external images ilso be seen. If we wish to shut these out, see only their central stereoscopic combina- we must use a diaphragm of paper held lel to the plane of the picture with a square n it. This paper screen must be so adjusted t may conceal the right-hand figure from ft eye, and the left-hand figure from the eye, while the central stereoscopic picture may be seen through the hole. It will be plain from the diagram that o is the point to which the eyes must be directed, and at which they will imagine the point to be situated, which is formed by the combination of the two points r and l. The dotted line shows the position of the screen. A stereoscope with or without lenses may easily be constructed, which will thus give us, with the ordinary stereoscopic slides, a reversed picture. For instance, if the subject be a landscape, the foreground will retire and the background come forward.

When the two retinas view simultaneously two different colours, the impression produced is that of a single mixed tint. The power, however, of combining the two tints into a single one varies in different individuals, and in some is extremely weak. If two white discs at the base of the stereoscope be illuminated by two pencils of complementary colours, and if each coloured disc be looked at with one eye, a single white one is seen, showing that the sensation of white light may arise from two complementary and simultaneous chromatic impressions on each of the two retinas.

576. **Persistence of impressions on the retina.**—When an ignited piece of charcoal is rapidly rotated, we cannot distinguish it; the appearance of a circle of fire is produced; similarly, rain, in falling in drops, appears in the air like a series of liquid threads. In a rapidly rotating toothed wheel the individual teeth cannot be seen. But if, during darkness, the wheel be suddenly illuminated, as by the electric spark, the individual parts may be clearly made out. These various appearances are due to the fact that the impression of these images on the retina remains for some time after the object which has produced them has disappeared or become displaced. The duration of the persistence varies with the sensitiveness of the retina and the intensity of light. The following experiment is a further illustration of this property. A series of equal sectors are traced on a disc of glass, and they are alternately blackened; in the centre there is a pivot, on which a second disc is fixed of the same dimensions as the first, but completely blackened, with the exception of a single sector; then placing the apparatus between a window and the eye, the second disc is made to rotate. If the movement is slow, all the transparent sectors are seen, but only one at a time; by a more rapid rotation we see simultaneously two, three, or a greater number.

M. Plateau has investigated the duration of the impression by numerous similar methods, and has found that it is on the average half a second. Among many curious instances of these phenomena, the following i one of the most remarkable. If, after having looked at a brightly illumi minated window, the eyes are suddenly closed, the image remains for few instants—that is, a sashwork is seen consisting of luminous pane surrounded by dark frames: after a few seconds the colours become in terchanged, the same framework is now seen, but the frames are no bright, and the glasses are perfectly black; this new appearance m again revert to its original appearance.

The impression of colours remains as well as that of the form of o jects; for if circles divided into sectors are painted in different colou me confounded, and give the sensation of the colour which ult from their mixture. Yellow and red give orange ; blue and t ; the seven colours of the spectrum give white, as shown in disc (fig. 416).

number of pieces of apparatus are founded on the persistence on on the retina. Such are the *thaumatrope*, the *phenakistoscope*, *wheel*, the *kaleidophone*.

ccidental images.—A coloured object being placed upon a und, if it is steadily looked at for some time, the eye is soon the intensity of the colour enfeebled ; if now the eyes are owards a white sheet, or to the ceiling, an image will be seen ie shape as the object, but of the complementary colour (524) ; ch a one as united to that of the object would form white. For bject the image will be red ; if the object is yellow, the image let.

ntal colours are of longer duration in proportion as the object more brilliantly illuminated, and the object has been longer . When a lighted candle has been looked at for some time, es are turned towards a dark part of the room, the appearance ne remains, but it gradually changes colour ; it is first yellow, sses through orange to red, from red through violet to greenish h is gradually feebler until it disappears. If the eye which has ng at the light be turned towards a white wall, the colours fol- t the opposite direction : there is first a dark picture on a und, which gradually changes into blue, is then successively yellow, and ultimately cannot be distinguished from a white

son of this phenomenon is, doubtless, to be sought in the fact bsequent action of light on the retina is not of equal duration urs, and that the decrease in the intensity of the subsequent s not follow the same law for all colours.

radiation.—This is a phenomenon in virtue of which white those of a very bright colour, when seen on ound, appear larger than they really are. vhite square upon a black ground seems n an exactly equal black square upon a nd (fig. 469). Irradiation arises from the he impression produced on the retina ex- ond the outline of the image. It bears the ion to the space occupied by the image that on of the impression does to the time during image is seen.

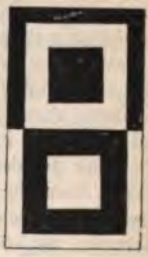


Fig. 469.

ct of irradiation is very perceptible in the nagnitude of stars, which may thus appear er than they really are ; also in the appear- moon when two or three days old, the brightly illuminated eming to extend beyond the darker portion of the disc, and hold sp.

Plateau, who has investigated this subject, finds that irradiation differs very much in different people, and even in the same person it differs on different days. He has also found that irradiation increases with the lustre of the object, and the length of time during which it is viewed. It manifests itself at all distances, diverging lenses increase it, condensing lenses diminish it.

Accidental haloes are the colours which, instead of succeeding the impression of an object like accidental colours, appear round the object itself when it is looked at fixedly. The impression of the halo is the opposite to that of the object; if the object is bright the halo is dark and *vice versâ.* These appearances are best produced in the following manner. A white surface, such as a sheet of paper, is illuminated by coloured light, and a narrow opaque body held so as to cut off some of the coloured rays. In this manner a narrow shadow is obtained which is illuminated by the surrounding white daylight, and appears complementary to the coloured ground. If red glass is used, the shadow appears green, and blue when a yellow glass is used.

The *contrast of colours* is a reciprocal action exerted between two adjacent colours, and in virtue of which to each one is added the complementary colour of the other. This contrast was observed by M. Chevreul, who has made it the subject of study. It is by the reciprocal influence of coloured shadows that the contrast of colour is explained.

M. Chevreul has found that when red and yellow colours are adjacent, red acquires a violet and orange a yellow tint. If the experiment is made with red and blue, the former acquires a yellow, and the latter a green tint: with yellow and blue, yellow passes to orange, and blue towards indigo: and so on for a vast number of combinations. The importance of this phenomenon in its application to the manufacture of cloths, carpets, etc., may be readily conceived.

579. **The eye is not achromatic.**—It had long been supposed that the human eye was perfectly achromatic, but this is clearly impossible, as all the refractions are made the same way, viz. towards the axis; moreover, the experiments of Wollaston, of Young, of Fraunhofer, and of Müller, have shown that it was not true in any absolute sense.

Fraunhofer showed that in a telescope with two lenses, a very fine wire placed inside the instrument in the focus of the object glass is seen distinctly through the eye-piece, when the telescope is illuminated with red light; but it is invisible by violet light even when the eye-piece is in the same position. In order to see the wire again, the distance of the lenses must be diminished to a far greater extent than would correspond to the degree of refrangibility of violet light in glass. In this case, therefore, the effect must be due to a chromatic aberration in the eye.

Müller, on looking at a white disc on a dark ground, found that the image is sharp when the eye is accommodated to the distance of the disc, that is, when the image forms on the retina; but he found that if the image is formed in front of or behind the retina, the disc appears surrounded by a very narrow blue edge.

If a finger be held up in front of one eye (the other being closed) in such a manner as to allow the light to enter only one-half of the pupil, and, of course, obliquely, and the eye be then directed to any well-defined line of light, such as a slit in the shutter of a darkened room, or a strip of white paper on a black ground, this line of light will appear as a complete spectrum.

Müller concluded from these experiments that the eye is sensibly achromatic as long as the image is received at the focal distance, or when it is accommodated to the distance of the object. The cause of this apparent achromatism cannot be exactly stated. It has generally been attributed to the tenuity of the luminous beams which pass through the pupillary aperture, and that these unequally refrangible rays, meeting the surfaces of the media of the eye almost at the normal incidence, are very little refracted, from which it follows that the chromatic aberration is imperceptible (534).

Spherical aberration, as we have already seen is corrected by the iris (563). The iris is in point of fact a diaphragm, which stops the marginal rays, and only allows those to pass which are near the axis.

580. **Short sight and long sight; myopy and presbytism.**—The most usual affections of the eye are *myopy* and *presbytism*, or *short sight* and *long sight*. Short sight is the habitual accommodation of the eyes for a distance less than that of ordinary vision, so that persons affected in this way only see very near objects distinctly. The usual cause of short sight is a too great convexity of the cornea or of the crystalline; the eye being then too convergent, the focus, in place of forming on the retina, is formed in front, so that the image is indistinct. It may be remedied by means of diverging glasses, which in making the rays deviate from their common axis throw the focus farther back, and cause the image to be formed on the retina.

The habitual contemplation of small objects, as when children are too much accustomed, in reading and writing, to place the paper close to their eyes, or working with a microscope, may produce short sight. It is common in the case of young people, but diminishes with age.

Long sight is the contrary of short sight: the eye can see distant objects very well, but cannot distinguish those which are very near. The cause of long sight is that the eye is not sufficiently convergent, and hence the image of objects is formed beyond the retina: but if the objects are removed farther off, the image approaches the retina, and when they are at a suitable distance is exactly formed upon it, so that the object is clearly seen.

Long sight is corrected by means of converging lenses. These glasses bring the rays together before their entrance into the eye, and, therefore, if the converging power is properly chosen, the image will be formed exactly on the retina.

It is not many years since double convex lenses were alone used for long-sighted persons, and double concave for short-sighted persons. Wollaston first proposed to replace these glasses by concavo-convex lenses, C and F (fig. 394), so placed that their curvature is in the same direction as that of the eye. By means of these glasses a much wider range is attained, and hence they have been called *periscopic glasses.*

581. **Eye-glasses. Spectacles.**—The glasses commonly used by short or long sighted persons are known under the general name of eye-glasses, or spectacles. Generally speaking, numbers are engraved on these glasses which express their focal length in *inches*.

The number which a short or long sighted person ought to use may be calculated, knowing the distance of distinct vision. The formula

$$f = \frac{pd}{d-p} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

serves for long-sighted persons, where f being the number which ought to be taken, p is the distance of distinct vision in ordinary cases (about 12 inches), and d the distance of distinct vision for the person affected by long sight.

The above formula is obtained from the equation $\frac{1}{p} - \frac{1}{p'} = \frac{1}{f}$ by substituting d for p'. In this case the formula (6) of article 517 is used, and not formula (5), because the image seen by spectacles being on the same side of the object in reference to the lens, the sign of p' ought to be the opposite of that of p, as in the case of virtual images from the paragraph already cited.

For short-sighted persons, f is calculated by the formula $\frac{1}{p} - \frac{1}{p'} = -\frac{1}{f}$ (517), which belongs to concave lenses, and which, replacing p' by d, gives

$$f = \frac{pd}{p-d} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

To calculate, for instance, the number of a glass which a person ought to use in whom the distance of distinct vision is 36, knowing that the distance of ordinary distinct vision is 12 inches; making $p = 12$ and $d = 36$ in the above formula (1), we get $f = \frac{36 \times 12}{36 - 12} = 18$.

582. **Diplopy.**—Diplopy is an affection of the eye which causes objects to be seen double, that is, that two images are seen instead of one. Usually the two images are almost entirely superposed, and one of them is much more distinct than the other. Diplopy may be caused by the co-operation of two unequal eyes, but it may also affect a single eye. The latter case is, doubtless, due to some defect of conformation in the crystalline or other parts of the eye which produces a bifurcation of the luminous ray, and thus two images are formed on the retina instead of one. A single eye may also be affected with *triplopy*, but in this case the third image is exceedingly weak.

583. **Achromatopsy : Daltonism.**—*Achromatopsy*, or *colour disease*, is a curious affection which renders us incapable of distinguishing colours, or at any rate certain colours. In some cases the insensibility is complete, while in others some colours can be very well distinguished. Persons affected

in this manner can distinguish the outlines of bodies without difficulty, and they can also discriminate between light and shade, but they are unable to distinguish the different tints.

D'Hombres-Firmas cites an instance of a person affected with achromatopsy, who had painted in a room a landscape of which the ground, trees, houses, and men were all painted blue, and when asked why he had not given each its proper colour, he replied that he wished to assimilate the colour of his drawing to that of his furniture; now this was red.

Achromatopsy is also sometimes called *Daltonism*, because Dalton, who has carefully described it, was so affected.

584. **Ophthalmoscope.**—This instrument, as its name indicates, is designed for the examination of the eye, and was invented in 1851 by Prof. Helmholtz. It consists :—1. Of a concave spherical reflector of glass or metal, M (figs. 470, 471), in the middle of which is a small hole about a sixth of an inch in diameter. The focal length of the reflector is from 8 to 10 inches. 2. Of a converging achromatic lens, *o*, which is held in front of the eye of the patient. 3. Of several lenses, some convergent others divergent, any one of which can be fixed in a frame behind the mirror so as to correct any given imperfection in the observer's sight. If the mirror is of silvered glass, it is not necessary that it be pierced at the centre; it is sufficient that the silvering at the centre be removed.

To make use of the ophthalmoscope, the patient is placed in a darkened room, and a lamp furnished with a screen put beside him, E. The screen serves to shade the light from his head, and keep it in darkness. The observer A, holding in one hand the reflector, employs it to concentrate the light of the lamp near the eye B of the patient, and with his other hand holds the achromatic lens *o* in front of the eye. By this arrangement the back of the eye is lighted up, and its structure can be clearly discerned.

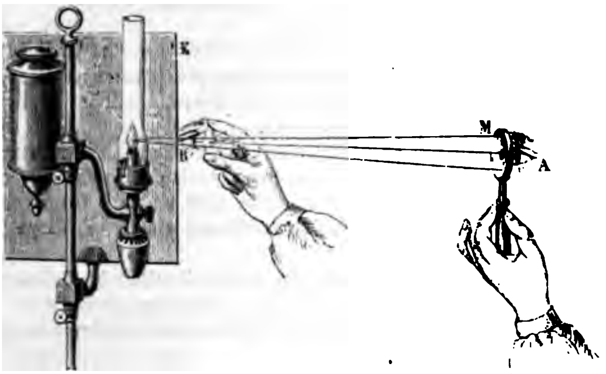


Fig. 470.

Fig. 471 shows how the image of the back of the eye is produced, which the observer A sees on looking through the hole in the reflector. Let ab be the part of the retina on which the light is concentrated, pencils of rays proceeding from ab would form an inverted and aërial image of ab at $a'b'$. These pencils, however, on leaving the eye, pass through the lens o, and thus the image $a''b''$ is in fact formed, inverted, but distinct, and in a position fit for vision.

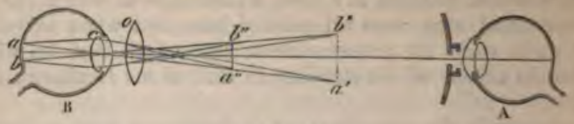


Fig. 471.

The great quantity of light concentrated by the ophthalmoscope is apt to irritate painfully the eye of the patient. There are, therefore, interposed between the lamp and the reflector coloured glasses, to cut off the irritating rays, viz., the red, yellow, and violet rays. The glasses generally employed are stained green or cobalt blue.

CHAPTER VII.

SOURCES OF LIGHT. PHOSPHORESCENCE.

585. **Various sources of light.**—The various sources of light are the sun, the stars, heat, chemical combination, phosphorescence, electricity, and meteoric phenomena. The last two sources will be treated under the articles *Electricity* and *Meteorology*.

The origin of the light emitted by the sun and by the stars is unknown; it is assumed that the ignited envelope by which the sun is surrounded is gaseous, because the light of the sun, like that emitted from all gaseous bodies, gives no trace of polarisation in the polarising telescope (Chapter VIII.).

As regards the light developed by heat, Pouillet has observed that bodies begin to be luminous in the dark at a temperature of 500° to 600°; above that the light is brighter in proportion as the temperature is higher.

The luminous effects witnessed in many chemical combinations are due to the high temperatures produced. This is the case with the artificial lights used for illuminations; for as we have already seen, luminous flames are nothing more than gaseous matters containing solids heated to the point of incandescence.

586. **Phosphorescence: its sources.**—*Phosphorescence* is the property which a large number of substances possess of emitting light when placed under certain conditions.

M. Becquerel, who has studied this subject in a very comprehensive manner, and has arrived at some extremely remarkable results, refers the phenomena to five causes :—

i. *Spontaneous phosphorescence* in certain vegetables and animals ; for nstance, it is very intense in the glow-worm and in the lampyre, and the rightness of their light appears to depend on their will. In tropical limates the sea is often covered with a bright phosphorescent light due o some extremely small zoophytes. These animalculæ emit a luminous natter so subtile that MM. Quoy and Gaimard, during a voyage under he equator, having placed two in a tumbler of water, the liquid imme-iately became luminous throughout its entire mass.

ii. *Phosphorescence by elevation of temperature.* This is best seen in ertain species of diamonds and in fluorspar, which, when heated to 300° r 400°, suddenly becomes luminous, emitting a bluish light.

iii. *Phosphorescence by mechanical effects,* such as friction, percussion. leavage, etc. : for example, when two crystals of quartz are rubbed gainst each other in darkness, or when a lump of sugar is broken.

iv. *Phosphorescence by electricity,* like that which results from the iction of mercury against the glass in a barometric tube, and especially om the electric sparks proceeding either from an ordinary electrical achine, or from a Ruhmkorff's coil.

v. *Phosphorescence by isolation or exposure to the sun.* A large number f substances, after having been exposed to the action of solar light, or of e diffused light of the atmosphere, emit in darkness a phosphorescence, e colour and intensity of which depend on the nature and physical con-ition of these substances. This kind of phosphorescence has been udied by M. Becquerel, an abstract of whose researches is given in the ext paragraph.

587. **Phosphorescence by insolation.**—This was first observed in 1604 Bolognese phosphorus (sulphide of barium), but M. Ed. Becquerel has lso discovered it in a great number of substances. The sulphides of lcium and strontium are those which present it in the highest degree. hen well prepared, after being exposed to the light, they are luminous r several hours in darkness. But as this phosphorescence takes place *vacuo* as well as in a gaseous medium, it cannot be attributed to a emical action, but rather to a temporary modification which the body dergoes from the action of light.

After the substances above named, the best phosphorescents are the llowing, in the order in which they are placed : a large number of dia-onds (especially yellow), and most specimens of fluorspar; then arrago-ite, calcareous concretions, chalk, apatite, heavy spar, dried nitrate of alcium, and dried chloride of calcium, cyanide of calcium, a large umber of strontium or barium compounds, magnesium and its carbo-ate, etc. Besides these a large number of organic substances also ecome phosphorescent by insolation ; for instance, dry paper, silk, cane-ugar, milk-sugar, amber, the teeth, etc.

Becquerel finds that the different spectral rays are not equally well tted to render substances phosphorescent. The maximum effect takes lace in the violet rays, or even a little beyond ; while the light emitted by phosphorescent bodies generally corresponds to rays of a smaller refrangibility than those of the light received by them, and giving rise to the action.

The tint which phosphorescent bodies assume is very variable, and even in the same body it changes with the manner in which it is prepared. In strontium compounds green and blue tints predominate; and orange, yellow, and green tints in the sulphides of barium.

The duration of phosphorescence varies also in different bodies. In the sulphides of calcium and strontium phosphorescence lasts as much as thirty hours; with other substances it does not exceed a few seconds, or even a fraction of a second.

Phosphoroscope. In experimenting with bodies whose phosphorescence lasts a few minutes or even a few seconds, it is simply necessary to expose them to solar or diffused light for a short time, and then place them in darkness: their luminosity is very apparent, especially if care has previously been taken to close the eyes for a few instants. But in the case of bodies whose phosphorescence lasts only a very short time, this method is inadequate. M. Becquerel has invented a very ingenious apparatus, the *phosphoroscope*, by which bodies can be viewed immediately after being exposed to light: the interval which separates the insolation and observation can be made as small as possible, and measured with great precision.

This apparatus, which is constructed by M. Duboscq, consists of a closed cylindrical box, AB (fig. 472), of blackened metal; on the ends there are two apertures opposite each other which have the form of a circular sector. Only one of these, *o*, is seen in the figure. The box is fixed, but it is traversed in the centre by a movable axis, to which are fixed two circular screens, MM and PP, of blackened metal (fig. 472). Each of these screens is perforated by four apertures of the same shape as those in the box; but while the latter correspond to each other, the apertures of the screens alternate, so that the open parts of the one correspond to the closed parts of the other. The two screens, as already mentioned, are placed in the box, and fixed to the axis, which by means of a train of wheels, worked by a handle, can be made to turn with any velocity.

In order to investigate the phosphorescence of any body by means of this instrument, the body is placed on a stirrup interposed between the two rotating screens. The light cannot pass at the same time through the opposite apertures of the sides A and B, because one of the closed parts of the screen MM, or of the screen PP, is always between them. So that when a body, *a*, is illuminated by light from the other side of the apparatus, it could not be seen by an observer looking at the aperture *o*, for then it would be masked by the screen PP. Accordingly, when an observer saw the body *a*, it would not be illuminated, as the light would be intercepted by the closed parts of the screen MM. The body *a* would alternately appear and disappear; it would disappear during the time of its being illuminated, and appear when it was no longer so. The time which elapses between the appearance and disappearance depends on the velocity of rotation of the screens. Suppose, for instance, that they made 150 turns in a second; as one revolution of the screens is effected in $\frac{1}{150}$ of a second, there would be four appearances and four disappearances during that time. Hence the length of time elapsing between the time of illumination and of observation would be $\frac{1}{8}$ of $\frac{1}{150}$ of a second or 0·0008 of a second.

Observations with the phosphoroscope are made in a dark chamber,

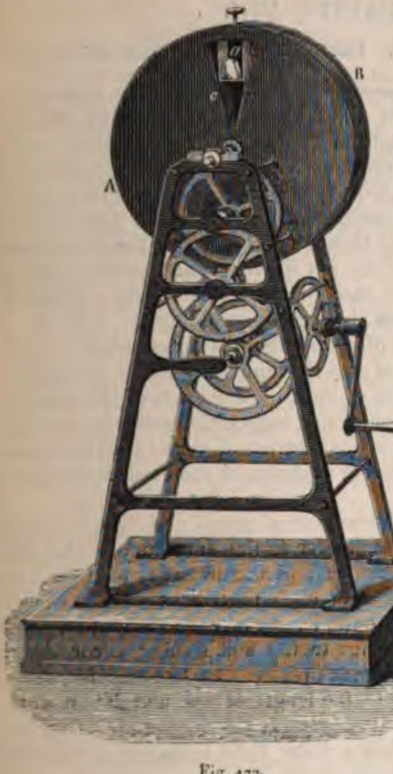


Fig. 472.

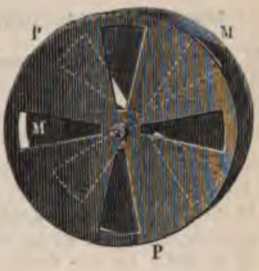


Fig. 473.

the observer being on that side on which is the wheelwork. A ray of solar or of electric light is allowed to fall upon the substance *a*, and the screens being made to rotate more or less rapidly, the body *a* appears uminous by transparence in a continuous manner, when the interval etween insolation and observation is less than the duration of the phos-horescence of the body. By experiments of this kind, Becquerel has und that substances which usually are not phosphorescent become so the phosphoroscope; such, for instance, is Iceland spar. Uranium ompounds present the most brilliant appearance in this apparatus; they emit a very bright luminosity when the observer can see them 0·003 or 0·004 of a second after insolation. But a large number of bodies present no effect in the phosphoroscope; for instance, quartz, sulphur, phosphorus, metals, and liquids.

CHAPTER VIII.

DOUBLE REFRACTION. INTERFERENCE. POLARISATION.

588. **The undulatory theory of light.**—It has been already stated (463) that the phenomenon of light is, with good reason, ascribed to undulations propagated through an exceedingly rare medium called the luminiferous ether, which is supposed to pervade all space, and to exist between the molecules of the ordinary forms of matter. In a word, it is held that light is due to the undulations of the ether, just as sound is due to undulations propagated through the air. In the latter case the undulations cause the drum of the ear to vibrate and produce the sensation of sound. In the former case the undulations cause points of the retina to vibrate and produce the sensation of light. The two cases differ in this, that in the case of sound there is independent evidence of the existence and vibration of the medium (air) which propagates the undulation, whereas in the case of light the existence of the medium and its vibrations are *assumed*, because that supposition connects and explains in the most complete manner a long series of very various phenomena. There is, however, no independent evidence of the existence of the luminiferous ether.

The analogy between the phenomena of sound and light is very close; thus, the intensity of a sound is greater as the amplitude of the vibration of each particle of the air is greater, and the intensity of light is greater as the amplitude of the vibration of each particle of the ether is greater. Again, a sound is more acute as the length of each undulation producing the sound is less, or, which comes to the same thing, according as the number of vibrations per minute is greater. In like manner, the colour of light is different according to the length of the undulation producing the light; a red light is due to a comparatively long undulation, and corresponds to a deep sound, while a violet light is due to a short undulation, and corresponds to an acute sound.

Although the length of the observations cannot be observed directly, yet they can be inferred from certain phenomena with great exactness. The following table gives the length of the undulations corresponding to the light at the principal dark lines of the spectrum. The lengths are given in decimals of an inch.

Dark Line	Length of Undulation
B	0·0000271
C	0·0000258
D	0·0000244
E	0·0000207
F	0·0000191
G	0·0000169
H	0·0000155

It will be remarked that the limits are very narrow within which the gths of the undulations of the ether must be comprised, if they are to capable of producing the sensation of light. In this respect light is in rked contrast to sound. For the limits are very wide within which lengths of the undulations of the air may be comprised when they duce the sensation of sound (229).

The undulatory theory readily explains the colours of different bodies. ording to that theory, certain bodies have the property of exciting lulations of different lengths, and thus producing light of given colours. ite light or daylight results from the coexistence of undulations of all sible lengths.

he colour of a body is due to the power it has of extinguishing certain ations, and reflecting others; and the body appears of the colour luced by the coexistence of the reflected vibrations. A body appears te when it reflects all different vibrations in the proportion in which are present in the spectrum: it appears black when it reflects light uch small quantities as not to affect the eye. A red body is one h has the property of reflecting in predominant strength those ations which produce the sensation of red. This is seen in the fact , when a piece of red paper is held against the daylight, and the re- ed light is caught on a white wall, this also appears red. A piece of paper in the red part of the spectrum appears of a brighter red, and ece of blue paper held in the blue part appears of a brighter blue; e a red paper placed in the violet or blue part appears almost black. he last case the red paper can only reflect red rays, while it extin- hes the blue rays, and as the blue of the spectrum is almost free from so little is reflected that the paper appears black.

he undulatory theory likewise explains the colours of transparent es. Thus, a vibrating motion on reaching a body sets it in vibration. lso the vibrations of the luminiferous ether are communicated to the r in a body, and setting it in motion produce light of different colours. n this motion is transmitted through any body, it is said to be *trans- nt* or *translucent*, according to the different degrees of strength with h this transmission is effected. In the opposite case it is said to be *ue.*

hen light falls upon a transparent body, the body appears colourless the vibrations are transmitted in the proportion in which they exist e spectrum. But if some of the vibrations are checked or extin- ed, the emergent light will be of the colour produced by the coexistence of the unchecked vibrations. Thus, when a piece of blue glass is held before the eye, the vibrations producing red and yellow are extinguished, and the colour is due to the emergent vibrations which produce blue light.

The undulatory theory also accounts for the reflection and refraction of light, as well as other phenomena which are yet to be described. The explanation of the refraction of light is of so much importance that we shall devote to it the following article.

589. **Physical explanation of single refraction.**—The explanation of this phenomenon by means of the undulatory theory of light presupposes that of the mode of propagation of a plane wave. Now, if a disturbance originated at any *point* of the ether, it would be propagated as a spherical wave in all directions round that point with a uniform velocity. If, instead of a single point, we consider the front of a plane wave, it is evident that disturbances originate simultaneously at all points of that front, and that spherical waves proceed from each *point* with the same uniform velocity. Consequently all these spheres will at any subsequent instant be touched by a plane parallel to the original plane. The disturbances propagated from the points in the first position of the wave will mutually destroy each other, except in the tangent plane; consequently the wave advances as a plane wave, its successive positions being the successive positions of the tangent plane. If the wave moves in the medium with a velocity v, it will describe a space vt in a time t.

Suppose the plane wave, AC (fig. 474), to move through vacuum and

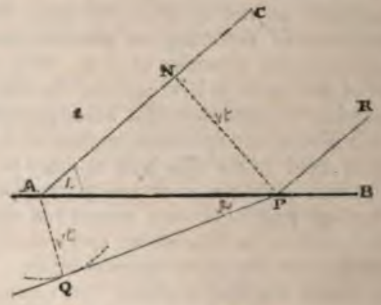


Fig. 474.

to meet the plane surface, AB, of an ordinary refracting medium at an angle CAB or I. Suppose the velocity of propagation *in vacuo* to be v, and in the medium to be v'. Now the wave entering the medium at A will after any time (t) be moving partly within and partly without the medium. Suppose PR to be the part outside the medium, draw PN at right angles to AC, then PN equals vt. Now in the same time, t, a spherical wave propagated from A, will have a radius $v't$; if, then, PQ is drawn touching a circle whose centre is A and whose radius AQ equals $v't$, then PQ will be the position of the plane wave within the medium at the instant under consideration. If we denote the angle APQ by R it is plain that

$$\text{Sin I} : \sin \text{R} :: \text{PN} : \text{AQ} :: vt : v't :: v : v'.$$

But a succession of parallel plane waves will give rise to a pencil of parallel rays at right angles to the waves; consequently, with respect to any one of these rays, I and R are the angles of incidence and refraction. Therefore the ratio of the sines of those angles is constant and equals $v : v'$, which is the distinctive law of single refraction.

Moreover, if μ is the refractive index of the substance, $v \div v'$ equals μ, that is, v equals $v' \mu$. Now, under all circumstances, μ is greater than 1, and therefore v is greater than v': a result which coincides with that obtained from experiment (470).

DOUBLE REFRACTION.

590. **Double refraction.**—It has been already stated (494), that a large number of crystals possess the property of double refraction, in virtue of which a single incident ray in passing through any one of them is divided into two, or undergoes *bifurcation*, whence it follows that, when an object is seen through one of these crystals, it appears double. The fact of the existence of double refraction in Iceland spar was first stated by Bartholin in 1669, but the law of double refraction was first enunciated exactly by Huyghens in his treatise on light written in 1678, and published in 1690.

Crystals which possess this peculiarity are said to be *double refracting*. It is found to a greater or less extent in all crystals which do not belong to the cubical system. Bodies which crystallise in this system, and those which, like glass, are destitute of crystallisation, have no double refraction. The property can, however, be imparted to them when they are unequally compressed, or when they are cooled quickly after having been heated, in which state glass is said to be annealed. Of all substances, that which possesses it most remarkably is Iceland spar or carbonate of calcium. In many substances the power of double refraction can hardly be proved to exist directly by the bifurcation of an incident ray; but its existence is shown indirectly by their being able to 'depolarise' light.

Fresnel has explained double refraction by assuming that the ether in double refracting bodies is not equally elastic in all directions; from which it follows that the vibrations, in certain directions at right angles to each other, are transmitted with unequal velocities; these directions being dependent on the constitution of the crystal. This hypothesis is confirmed y the property which glass acquires of becoming double refracting by eing unannealed and by pressure.

591. **Uniaxial crystals.**—In all double refracting crystals there is *one* irection, and in some a second direction possessing the following proerty. When a point is looked at through the crystal in this particular rection, it does *not* appear double. The lines fixing these directions e called *optic axes*; and sometimes, though not very properly, axes of

double refraction. A crystal is called *uniaxial* when it has *one* optic axis, that is to say, when there is one direction within the crystal along which a ray of light can proceed without bifurcation. When a crystal has *two* such axes, it is called a *biaxial* crystal.

The uniaxial crystals most frequently used in optical instruments are Iceland spar, quartz, and tourmaline. Iceland spar crystallises in rhombohedra, whose faces form with each other angles of 105° 5′ or 74° 55′. It has eight solid angles (see fig. 475). Of these two, situated at the extremities of one of the diagonals, are severally contained by three obtuse angles. A line drawn within one of these two angles in such a manner as to be equally inclined to the three edges containing the angle is called the *axis of the crystal*. If all the edges of the crystal were equal, the axis of the crystal would coincide with the diagonal, *ab*.

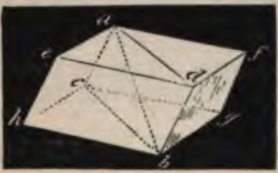


Fig. 475.

Brewster has shown that in all uniaxial crystals the optic axis coincides with the axis of crystallisation.

The principal plane with reference to a point of any face of a crystal, whether natural or artificial, is a plane drawn through the point at right angles to the face and parallel to the optic axis. If in fig. 475 we suppose the edges of the rhombohedron to be equal, the diagonal plane *abcd* contains the optic axis (*ab*), and is at right angles to the faces *acdf* and *chbg*; consequently, it is parallel to the principal plane at any point of either of those two faces. For this reason *acbd* is often called the principal plane with respect to those faces.

592. **Ordinary and extraordinary ray.**—Of the two rays into which an incident ray is divided on entering a uniaxial crystal, one is called the *ordinary* and the other the *extraordinary* ray. The ordinary ray follows the laws of single refraction, that is, with respect to that ray the sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction, and the plane of incidence coincides with the plane of refraction. Except in particular positions, the extraordinary ray follows neither of these laws. The images corresponding to the ordinary and extraordinary rays are called the ordinary and extraordinary images respectively.

If a transparent specimen of Iceland spar be placed over a dot of ink on a sheet of white paper, the two images will be seen. One of them, the ordinary image, will seem slightly nearer to the eye than the other, the extraordinary image. Suppose the spectator to view the dot in a direction at right angles to the paper, then, if the crystal, with the face still on the paper, be turned round, the *ordinary* image will continue fixed, and the extraordinary image will describe a circle round it, the line joining them being always in the direction of the shorter diagonal of the face of the crystal, supposing its edges to be of equal length. In this case it is found that the angle between the ordinary and extraordinary ray is 6° 12′.

593. **The laws of double refraction in a uniaxial crystal.**—These phenomena are found to obey the following laws :—

i. Whatever be the plane of incidence, the ordinary ray always obeys two general laws of single refraction (494). The refractive index for ordinary ray is called the ordinary refractive index.

ii. In every section perpendicular to the optic axis the extraordinary also follows the laws of single refraction. Consequently in this plane extraordinary ray has a constant refractive index, which is called the raordinary refractive index.

iii. In every principal section the extraordinary ray follows the second only of single refraction, that is, the planes of incidence and refraction ncide, but the ratio of the sines of the angles of incidence and refraction not constant.

v. The velocities of light along the rays are unequal. It can be shown t the difference between the squares of the reciprocals of the velocities ng the ordinary and extraordinary rays is proportional to the square of sine of the angle between the latter ray and the axis of the crystal.

There is an important difference between the velocity of the *ray* and velocity of the corresponding *plane wave*. If the velocities of the ne waves corresponding to the ordinary and extraordinary rays are sidered, the difference between the squares of these velocities is protional to the square of the sine of the angle between the axis of the stal and the normal to that plane wave which corresponds to the exordinary ray. The normal and the ray do not generally coincide.

Huyghens gave a very remarkable geometrical construction, by means which the directions of the refracted rays can be determined when the ections of the incident ray and of the axis are known relatively to the e of the crystal. This construction was not generally accepted by sicists until Wollaston and subsequently Malus showed its truth by merous exact measurements.

94. **Positive and negative uniaxial crystal.**—The term extrainary refractive index has been defined in the last article. For the ne crystal its magnitude always differs from that of the *ordinary* refractive index; for example, in Iceland spar the ordinary refractive index 1·654, while the extraordinary refractive index is 1·483. In this case ordinary index exceeds the extraordinary index. When this is the se, the crystal is said to be negative. On the other hand, when the traordinary index exceeds the ordinary index, the crystal is said to be sitive. The following list gives the names of some of the principal iaxial crystals :—

Negative Uniaxial Crystals.

- Iceland spar
- Spathose Iron
- Tourmaline
- Sapphire
- Ruby
- Emerald
- Apatite
- Pyromorphite
- Ferrocyanide of potassium
- Nitrate of sodium

Positive Uniaxial Crystals.

- Zircon
- Quartz
- Apophyllite
- Ice
- Titanite
- Boracite

595. **Double refraction in biaxial crystals.**—A large number of crystals, including all those belonging to the *trimetric*, the *monoclinic*, and the *triclinic* systems, possess two *optic axes*; in other words, in each of these crystals there are two directions along which a ray of light passes without bifurcation. A line bisecting the acute angle between the optic axes is called the medial line; one that bisects the obtuse angle is called the supplementary line. It has been found that the medial and supplementary lines and a third line at right angles to both are closely related to the fundamental form of the crystal to which the optic axes belong. The acute angle between the optic axes is different in different crystals. The following table gives the magnitude of this angle in the case of certain crystals :—

Nitre	5° 20′	Anhydrite . . .	28° 7′
Strontianite . .	6 56	Heavy spar . . .	37 42
Arragonite . . .	18 18	Mica	45 0
Brazilian topaz . .	49 50	Kyanite . . .	81 48
Sugar	50 0	Epidote . . .	84 19
Selenite . . .	60 0	Sulphate of iron . .	90 0

When a ray of light enters a biaxial crystal, and passes in any direction not coinciding with an optic axis, it undergoes bifurcation; in this case, however, neither ray conforms to the laws of single refraction, but both are extraordinary rays. To this general statement the following exception must be made. In a section of a crystal at right angles to the medial line one ray follows the law of ordinary refraction, and in a section at right angles to the supplementary line the other ray follows the laws of ordinary refraction.

INTERFERENCE AND DIFFRACTION.

596. **Interference of light.**—The name *interference* is given to the mutual action which two luminous rays exert upon each other when they are emitted from two neighbouring sources, and meet each other under a very small angle. This action may be observed by means of the following experiment. In the shutter of a dark room two very small apertures are made, of the same diameter, at a very slight distance from each other. The apertures are closed by pieces of coloured glass—red, for example—by which two pencils of homogeneous light are introduced. These two pencils form two divergent luminous cones, which meet at a certain distance; they are received on a white screen a little beyond the place at which they meet, and in the segment common to the two discs which form upon this screen some very well-defined alternations of red and black bands are seen. If one of the two apertures be closed, the fringes disappear, and are replaced by an almost uniform red tint. From the fact that the dark fringes disappear when one of the beams is intercepted, it is concluded that they arise from the interference of the two pencils which cross obliquely.

This experiment was first made by Grimaldi, but was modified by ung. Grimaldi had drawn from it the conclusion that light added to ht produced darkness. The full importance of this principle remained a long time unrecognised, until these enquiries were resumed by Young d Fresnel, of whom the latter, by a modification of Grimaldi's experi- nt, rendered it an *experimentum crucis* of the truth of the undulatory pothesis.

In Grimaldi's experiment diffraction (597) takes place; for the luminous ys pass by the edge of the aperture. In Fresnel's experiment the two ncils interfere without the possibility of diffraction.

Two plane mirrors, AB and BC (fig. 476), of metal, are arranged close

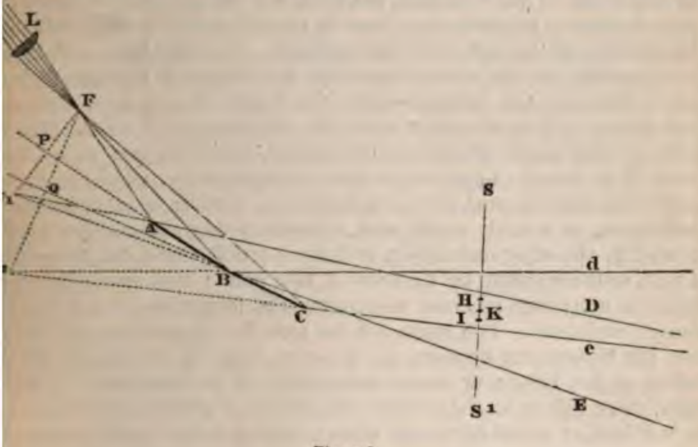


Fig. 476.

ach other, so as to form a very obtuse angle, ABC, which must be y little less than 180°. A pencil of red light, which passes into the k chamber, is brought, by means of a lens, L, to a focus F. On erging from F the rays fall partly on AB, and partly on BC. If BA roduced to P and FPF_1 is drawn at right angles to AP, and if PF_1 is de equal to PF, then the rays which fall on AB will, after reflection, ceed as if they diverged from F_1. If a similar construction is made the rays falling on BC, they will proceed after reflection as if they erged from F_2. A little consideration will show that F_1 and F_2 are y near each other. Suppose the reflected rays to fall on a screen SS_1 ced nearly at right angles to their directions. Every point of the en which receives light from both pencils is illuminated by two rays, one from F_1, the other from F_2; thus the point H is illuminated by rays, as also are K and I. Now the combined action of these two cils is to form a series of parallel bands alternately light and dark on screen at right angles to the plane of the paper. This is the funda- ital phenomenon of interference, and that it results from the *joint on of the two pencils* is plain, since, if the light which falls upon either e mirrors is cut off, the dark bands disappear.

This remarkable fact is explained in the most satisfactory manner the undulatory theory of light. The explanation exactly resembles th already given of the formation of nodes and loops by the combined acti of two aërial waves (251); the only difference being that in that ca the vibrating particles were supposed to be particles of air, whereas, the present case, the vibrating particles are supposed to be those of t luminiferous ether. Consider any point K on the screen, and first let suppose the distances of K from F_1 and F_2 to be equal. Then the u dulations which reach K will always be in the same *phase*, and t particle of ether at K will vibrate as if the light came from one sourc the amplitude of the vibration, however, will be increased in exactly t same manner as happens at a loop or ventral point; consequently at the intensity of the light will be increased. And the same will be tr for all points on the screen, such that the difference between their di tances from the two images equals the length of *one*, *two*, *three*, et undulations. If, on the other hand, the distances of K from F_1 and differ by the length of half an undulation, then the two waves wou reach K in exactly opposite phases. Consequently, whatever veloci would be communicated at any instant to a particle of ether by the o undulation, an exactly equal and opposite velocity would be comm nicated by the other undulation, and the particle would be *permanent* at rest, or there would be darkness at that point; this result being pr duced in a manner precisely resembling the formation of a *nodal* poi already explained. The same will be true for all positions of K, suc that the differences between its distances from F_1 and F_2 equal thre halves, or five halves, or seven halves, etc., of an undulation. Accor ingly, there will be on the screen a succession of alternations of light an dark points, or rather lines—for what is true of points in the plane of th paper (fig. 476) will be equally true of other points on the screen whic is supposed to be at right angles to the plane of the paper. Between th light and dark lines the intensity of the light will vary, increasing gr dually from darkness to its greatest intensity, and then decreasing to th second dark line, and so on.

If instead of red light any other coloured light were used, for examp violet light, an exactly similar phenomenon would be produced, but th distance from one dark line to another would be different. If white lig were used, each separate colour tends to produce a different set of da lines. Now these sets being superimposed on each other, and not co ciding, the dark lines due to one colour are illuminated by other colou and instead of dark lines a succession of coloured bands is produce The number of coloured bands produced by white light is much small than the number of dark lines produced by a homogeneous light; sin at a small distance from the middle band the various colours are co pletely blended, and a uniform white light produced.

597. **Diffraction and fringes.**—Diffraction is a modification whi light undergoes when it passes the edge of a body, or when it traver a small aperture; a modification in virtue of which the luminous ra appear to become bent, and to penetrate into the shadow.

'his phenomenon may be observed in the following manner : A beam solar light is allowed to pass through a very small aperture in the tter of a dark room, where it is received on a condensing lens, L (fig.), with a short focal length. A red glass is placed in the aperture

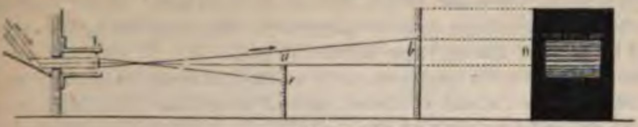


Fig. 477.

ıs only to allow red light to pass. An opaque screen, *e*, with a sharp e, is placed behind the lens beyond its focus, and intercepts one por- of the luminous cone, while the other is projected on the screen *b*, which B represents a front view. The following phenomena are now n : Within the geometrical shadow, the limit of which is represented the line *ab*, a faint light is seen, which gradually fades in proportion t is farther from the limits of the shadow. In this part of the screen ich, being above the line *ab*, might be expected to be uniformly illu- ated a series of alternate dark and light bands or fringes are seen allel to the line of shadow, which gradually become more indistinct ultimately disappear. The limits between the light and dark fringes not quite sharp lines; there are parts of maximum and minimum ensity which gradually fade off into each other.

All the colours of the spectrum give rise to the same phenomenon. but fringes are broader in proportion as the light is less refrangible. us, with red light they are broader than with green, and with green n with violet. Hence, with white light, which is composed of ferent colours, the dark spaces of one tint overlap the light spaces of other, and thus a series of prismatic colours will be produced.

If, instead of placing the edge of an opaque body between the light d the screen, a very narrow body be interposed, such as a hair or a e metallic wire, the phenomena will be different. Outside the space rresponding to the geometrical shadow, there is a series of fringes, as the former case. But within the shadow also there is a series of ternate light and dark bands. They are called interior fringes, and re much narrower and more numerous than the external fringes.

When a small opaque circular disc is interposed, its shadow on the reen shows in the middle a bright spot surrounded by a series of loured concentric rings; the bright spot is of various colours according the relative positions of the disc and screen. The haloes some- imes seen round the sun and moon belong to this class of pheno- ena. They are due, as Fraunhofer has shown, to the diffraction of ght by small globules of fog in the atmosphere. Fraunhofer has even ven a method of estimating the mean diameter of these globules from e dimensions of the haloes. A beautiful phenomenon of the same kind produced by looking at a flame through lycopodium powder strewed on ass.

spores of a moss.

598. **Gratings.**—Phenomena of diffraction of another class a duced by allowing the pencil of light from the luminous p traverse an aperture in an opaque screen. The diffracted light r received on a sheet of white paper, but the images are much bett through a small telescope placed behind the aperture. If the ape very small, the telescope may be dispensed with, and the figure viewed by placing the aperture before the eye.

Some of the simpler apertures, such as straight lines, triangles, or circles, may be cut out of tinfoil pasted on glass. Gratings obtained either by a series of fine equidistant wires, or by carefu on a piece of smo pertures of any form may be p

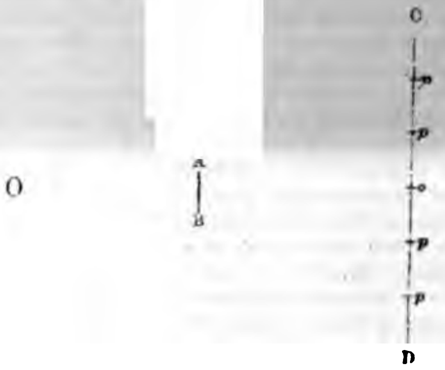


Fig. 478.

with great accuracy by taking on glass a collodion picture of a s paper on which the required forms are drawn in black.

Looking through any of these apertures, we see the luminou surrounded with coloured spectra of very various forms, and c beauty.

The beautiful colours seen on looking through a bird's feath distant source of light, and the colours of striated surfaces, s mother-of-pearl, are due to a similar cause.

The whole of these phenomena are in exact accordance with th latory theory, but the explanation is in many cases difficult.

The case of *gratings* is more simple and important than the oth therefore shall be considered in detail.

If a series of fine equidistant lines ruled on glass, or a series equidistant wires, be placed before the eye or before a telescope distant point or line of light be viewed through the grating thus we see on each side of the bright point or line a series of equ spectra, all having their violet ends directed inwards.

To explain these appearances, let us suppose the telescope removed, id the spectra received on a distant screen.

In figure 478 let O represent the luminous point, AB the grating, and D the distant screen.

We conceive of the effect on the screen of the light transmitted rough the grating in the following manner. The ether in the transrent intervals of the grating becomes simultaneously disturbed and ept in vibration by the light from O. The disturbance of each point those intervals becomes the origin of a spherical wave, as in art. 589, id the effect produced at any point of the screen is the sum of the effects ie to the action of the waves thus proceeding from all the transparent tervals. Now, at the point *o*, which is equidistant from all parts of e grating, all these waves will arrive in the same phase, and will, therere, reinforce each other, and give a bright point.

At other points, *pp*, on each side of *o*, whose distance from successive tervals of the grating differ by one wave length, or any whole number f wave lengths, the vibrations will also arrive in the same phase, and roduce brightness. But at intermediate points the vibrations will arrive om different points of the grating in all phases, and will, therefore, eutralise each other and give rise to darkness.

The fact that the spectra on each side of the central one are coloured rises from the wave lengths being different for different colours; and e measurement of the distances between the spectra corresponding to ifferent colours affords the most accurate method of determining these ave lengths.

599. **Colours of thin plates. Newton's rings.**—All transparent odies, solids, liquids, or gases, when in sufficiently fine laminæ, appear oloured with very bright tints, especially by reflection. Crystals which leave easily, and can be attained in very thin plates, such as mica and elenite, show this phenomenon, which is also well seen in soap-bubbles. drop of oil spread rapidly over a large sheet of water exhibits all the olours of the spectra in a constant order. A soap-bubble appears white t first, but in proportion as it is blown out, brilliant iridescent colours ppear, especially at the top, where it is thinnest. These colours are rranged in horizontal zones around the summit, which appears black hen there is not thickness enough to reflect light, and the bubble then uddenly bursts.

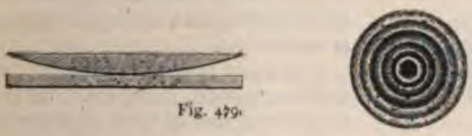


Fig. 479.

Newton, who first studied the phenomena of the coloured rings in soapubbles, wishing to investigate the relation between the thickness of the in plate, the colour of the rings, and their extent, produced them by means of a layer of air interposed between two glasses, one plane and the other convex, and with a very long focus. The two surfaces being cleaned and exposed in ordinary light in front of a window, so as to reflect light, there is seen at the point of contact a black spot surrounded by six or seven coloured rings, the tints of which become gradually less strong. If the glasses are viewed by transmitted light, the centre of the rings is white, and each of the colours is exactly complementary of that of the rings by reflection.

With homogeneous light, red for example, the rings are successively black and red ; the diameters of corresponding rings are less as the colour is more refrangible, but with white light the rings are of the different colours of the spectrum, which arises from the fact that, as the rings of the different simple colours have different diameters, they are not exactly superposed, but are more or less separated.

If the focal length of the lens is from three to four yards, the rings can be seen with the naked eye ; but if the length is less, the rings must be looked at with a lens.

600. **Explanation of Newton's rings.**—Newton's rings, and all phenomena of thin plates, are simple cases of interference.

In fig. 480, let MNOP represent a thin plate of a transparent body, on which a pencil of parallel rays of homogeneous light, *ab*, impinges ; this will be partially reflected in the direction *bc*, and partially refracted towards *d*. But the refracted ray will undergo a second reflection at the surface, OP ; the reflected ray will emerge at *e* in the same direction as the pencil of light reflected at the first surface ; and consequently the two pencils *bc* and *ef* will destroy or augment each other's effect according as they are in the same or different phases. We shall thus have an effect produced similar to that of the fringes.

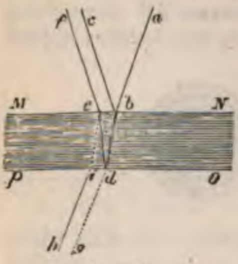


Fig. 480.

It is usual to speak of the successive rings as the first, second, third, etc. By the *first* ring is understood that of least diameter. Newton determined by calculation the thickness of the layer of air at the points where the successive rings were formed, and found that the thicknesses corresponding to the successive dark rings are proportional to the numbers 0, 2, 4, 6 . . . . . . , while for the *bright* rings the thicknesses were proportional to 1, 3, 5 . . . . . He found that for the first bright ring the thickness was $\frac{1}{178000}$ of an inch, when the light used was the brightest part of the spectrum, that is the part on the confines of the orange and yellow rays. He further found that for rings of the same order the diameter is greater as the refrangibility of the light producing it is less.

POLARISATION OF LIGHT.

'olarisation by double refraction.—It has been already seen
en a ray of light passes through a crystal of Iceland spar, it
divided into two rays of *equal intensity*, viz. the ordinary ray,
extraordinary ray. These rays are found to possess other pecu-
which are expressed by saying they are *polarised*, namely, the
ray in a principal plane, and the extraordinary ray in a plane at
gles to a principal plane. The phenomena which are thus desig-
ay be described as follows:—Suppose a ray of light which has
ne *ordinary* refraction in a crystal of Iceland spar to be allowed
through a second crystal, it will generally be divided into two
mely, one ordinary, and the other extraordinary, but of *unequal
es.* If the second crystal be turned round until the two principal
oincide, that is, until the crystals are in similar or in opposite
s, then the extraordinary ray disappears, and the ordinary ray is
eatest intensity; if the second crystal is turned further round, the
linary ray reappears, and increases in intensity as the angle in-
while the ordinary ray diminishes in intensity until the principal
re at right angles to each other, when the extraordinary ray is
reatest intensity, and the ordinary ray vanishes. These are the
ena produced when the ray which experienced ordinary refraction
rst crystal passes through the second. If the ray which has ex-
d extraordinary refraction in the first crystal is allowed to pass
the second crystal, the phenomena are similar to those above
d, but when the principal planes coincide, an extraordinary ray
nerges from the second crystal, and when the planes are at right
an ordinary ray alone emerges.

phenomena may also be thus described:—Let O and E denote the
and extraordinary rays produced by the first crystal. When O
he second crystal, it generally gives rise to two rays, an ordinary
d an extraordinary (O*e*), of unequal intensities. When E enters
nd crystal, it likewise gives rise to two rays, viz. an ordinary (E*o*),
extraordinary (E*e*), of unequal intensities; the intensities varying
angle between the principal planes of the crystals. When the
l planes coincide, only two rays, viz. O*o* and E*e*, emerge from
nd crystal, and when the planes are at right angles, only two rays,
and E*o*, emerge from the second crystal. Since O gives rise to
ary ray when the principal planes are parallel, and E gives rise
dinary ray when they are at right angles, it is manifest that O is
to the principal plane in the same manner that E is related to a
right angles to a principal plane.

phenomenon, which is produced by all double refracting crystals,
erved by Huyghens in Iceland spar, and in consequence of a
on of Newton's was afterwards called *polarisation.* It remained,
, an isolated fact until the discovery of polarisation by reflection
the attention of physicists to the subject. The latter discovery
de by Malus in 1808.

602. **Polarisation by reflection.**—When a ray of light, *ab* (f
falls on a polished unsilvered glass surface, *fghi*, inclined to it at a
of 35° 25′, it is reflected, and the refle
is polarised in the plane of reflectio
were transmitted through a crystal
land spar, it would be transmitted
bifurcation, and undergo an ordinar
tion, when the principal plane coinci
the plane of reflection; it would
transmitted without bifurcation but
extraordinary refraction, when the p
plane is at right angles to the p
reflection; in other positions of the
it would give rise to an ordinary
extraordinary ray of different intensi
cording to the angle between the p
reflection and the principal plane
crystal. The peculiar property wh
light has acquired by reflection
surface *fghi* can also be exhibited as follows:—Let the polarised
be received at *c*, on a second surface of unsilvered glass, at th
angle, viz. 35° 25′. If the surfaces are parallel, the ray is re
but if the second plate is caused to turn round *cb*, the intensity
reflected ray continually diminishes, and when the glass surface
right angles to each other, no light is reflected. By continuing
the upper mirror, the intensity of the reflected ray gradually increa
attains a maximum value when the surfaces are again parallel.

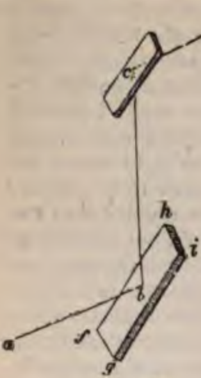


Fig. 481.

The above statement will serve to describe the phenomenon of
sation by reflection so far as the principles are concerned; the ap
best adapted for exhibiting the phenomenon will be described far

603. **Angle of polarisation.**—The polarising angle of a subst
the angle which the incident ray must make with the normal to
polished surface of that substance in order that the polarisation b
plete. For glass this angle is 54° 35′, and if in the preceding exp
the lower mirror were inclined at any other angle than this, th
would not be completely polarised in any position; this would be
by its being partially reflected from the upper surface in all po
Such light is said to be *partially polarised.* The polarising an
water is 52° 45′; for quartz, 57° 32′; for diamond, 68°; and it is 56
obsidian, a kind of volcanic glass which is often used in these exper

Light which is reflected from the surface of water, from a sla
from a polished table, is all more or less polarised. The ordinary
the atmosphere is frequently polarised, especially in the earlier an
periods of the day, when the solar rays fall obliquely on the atmo
Almost all reflecting surfaces may be used as polarising mirrors. M
surfaces form, however, an important exception.

Brewster has discovered the following remarkably simple law i
ence to the polarising angle:—

olarising angle of a substance is that angle of incidence for which cted polarised ray is at right angles to the refracted ray.

, in fig. 482, if *si* is the incident, *ir* the refracted, and reflected ray, the polarisation is mplete when *fi* is at right angles

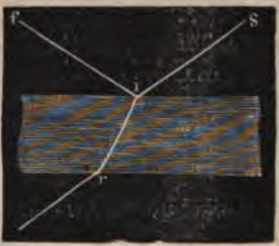


Fig. 482.

plane of polarisation is the plane ction in which the light becomes ed; it coincides with the plane of ce, and, therefore, contains the ing angle.

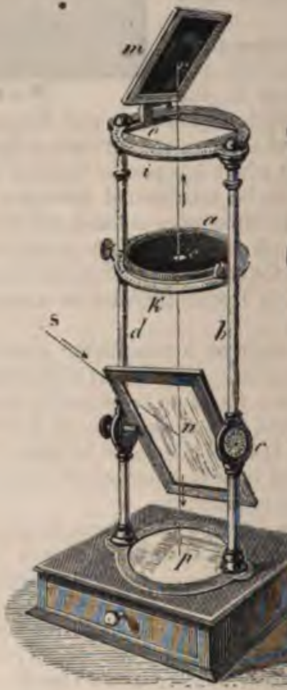
Polarisation by single refraction. n an unpolarised luminous ray pon a glass plate placed at the ng angle, one part is reflected; the other part, in passing through ss, becomes refracted, and the transmitted light is now found to be y polarised. If the light which has passed through one plate, and polarisation is very feeble, be transmitted through a second plate l to the first, the effects become more marked, and by ten or twelve are tolerably complete. A bundle of such plates, for which the aterial is the glass used for covering microscopic objects, fitted in at the polarising angle, is frequently used for examining or pro- polarised light.

ray of light fall at any angle on a transparent medium, the same ood with a slight modification. In fact, part of the light is reflected rt refracted, and both are found to be partially polarised, *equal ies in each being polarised, and their planes of polarisation being t angles to each other.* It is, of course, to be understood that the ed portion of the reflected light is polarised in the plane of reflec- hich is likewise the plane of refraction.

Polarising instruments.—Every instrument for investigating the ies of polarised light consists essentially of two parts, one for ng the light, the other for ascertaining or exhibiting the fact of ving undergone polarisation. The former part is called the pola- e latter the analyser. Thus in art. 601 the crystal producing the raction is the *polariser,* that producing the second refraction is the *r.* In art. 602, the mirror at which the first reflection takes place polariser, that at which the second reflection takes place is the r. Some of the most convenient means of producing polarised ll now be described, and it will be remarked that any instrument n be used as a polariser can also be used as an analyser. The ex- nter has therefore considerable liberty of selection.

Norremberg's apparatus.—The most simple but complete in- nt for polarising light is that invented by M. Norremberg. It used for repeating most of the experiments on polarised light. nsists of two brass rods *b* and *d* (fig. 483), which support an un- mirror, *n*, of ordinary glass, moveable about a horizontal axis. A

small graduated circle indicates the angle of inclination of the mi
Between the feet of the two columns there is a silvered glass, *p*, whi
fixed and horizontal. At the upper end of the columns there is a
duated plate, *i*, in which a circular disc, *o*, rotates. This disc, in which
is a square aperture, supports a mirror of black glass, *m*, which is inc
to the vertical at the polarising angle. An annular disc, *k*, can be
at different heights on the columns by means of a screw. A second
a, may be moved around the axis. It supports a black screen, i
centre of which there is a circular aperture.



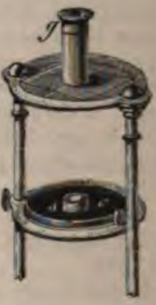


Fig. 484

Fig. 483

When the mirror *n* makes with the vertical an angle of 35° 25',
is the complement of the polarising angle for glass, the luminous ray
which meet the mirror at this angle, become polarised, and are refl
in the direction *np* towards the mirror *p*, which sends them in the
tion *pnr*. After having passed through the glass, *n*, the polarise
falls upon the blackened glass *m* under an angle of 35° 25', becaus
mirror makes exactly the same angle with the vertical. But if the di
to which the mirror, *m*, is fixed, be turned horizontally, the intensi

he light reflected from the upper mirror gradually diminishes, and totally disappears when it has been moved through 90°. This position is that epresented in the diagram: the plane of incidence on the upper mirror s then perpendicular to the plane of incidence, *Snp*, on the mirror *n*. When the upper mirror is again turned, the intensity of the light increases until it has passed through 180°, when it again reaches a maximum. The mirrors *m* and *n* are then parallel. The same phenomena are repeated as the mirror *m* continues to be turned in the same direction, until it again comes into its original position. The intensity of the reflected light being greatest when the mirrors are parallel, and being reduced to zero when they are at right angles. If the mirror *m* is at a greater or less angle than 35° 25′, a certain quantity of light is reflected in all positions of the plane of incidence.

607. **Tourmaline.**—The primary form of this crystal is a regular hexagonal prism. Tourmaline, as already stated, is a negative uniaxial crystal, and its optic axis coincides with the axis of the prism. For optical purposes a plate is cut from it parallel to the axis. When a ray of light passes through such a plate, an ordinary ray and an extraordinary ray are produced, polarised in planes at right angles to each other, viz. the former in a plane at right angles to the plate parallel to the axis, and the latter in a plane at right angles to the axis. The crystal possesses, however, the remarkable property of rapidly absorbing the ordinary ray; consequently, when a plate of certain thickness is used, the extraordinary ray alone emerges—in other words, a beam of common light emerges from the plate of tourmaline polarised in a plane at right angles to the axis of the crystal. If the light thus transmitted be viewed through another similar plate held in a parallel position, little change will be observed, excepting that the intensity of the transmitted light will be about equal to that which passes through a plate of double the thickness; but if the second tourmaline be slowly turned, the light will become feebler, and will ultimately disappear when the axes of the two plates are at right angles.

The objections to the use of the tourmaline are that it is not very transparent, and that plates of considerable thickness must be used if the polarisation is to be complete. For unless the ordinary ray is completely absorbed, the emergent light will be only partially polarised.

Mr. Herepath has lately discovered that sulphate of iodoquinine has the property of polarising light in a remarkable degree. Unfortunately, it is very fragile and difficult to obtain in large crystals.

608. **Double refracting prisms of Iceland spar.**—When a ray of light passes through an ordinary rhombohedron of Iceland spar, the ordinary and extraordinary rays emerge parallel to the original ray, consequently the separation of the rays is proportional to the thickness of the prism. But if the crystal is cut so that its faces are inclined to each other, the deviations of the ordinary and extraordinary rays will be different, they will not emerge parallel, and their separation will be greater as their distance from the prism increases. The light, however, in passing through the prism becomes decomposed, and the rays will be

coloured. It is therefore necessary to achromatise the prism, which is done by combining it with a prism of glass with its refracting angle turned in the contrary direction (fig. 485). In order to obtain the greatest amount of divergence, the refracting edges of the prism should be cut parallel to the optic axis, and this is always done.

Fig. 485.

Let us suppose that a ray of polarised light passes along the axis of the cylinder (fig. 485), and let us suppose that the cylinder is caused to turn slowly round its axis; then the resulting phenomena are exactly like those already described (599). Generally there will be an ordinary and extraordinary ray produced, whose relative intensities will vary as the tube is turned. But in two opposite positions the ordinary ray alone will emerge, and in two others at right angles to the former the extraordinary ray will alone emerge. When the ordinary ray alone emerges, the principal plane of the crystal—that is, a plane at right angles to its face, and parallel to its refracting edge—coincides with the original plane of polarisation of the ray. Consequently, by means of the prism, it can be ascertained both that the ray is polarised, and likewise the plane in which it is polarised.

601 ?

609. **Nicol's prism.**—The Nicol's prism is one of the most valuable means of polarising light, for it is perfectly colourless, it polarises light completely, and it transmits only one beam of polarised light, the other being entirely suppressed.

It is constructed out of a rhombohedron of Iceland spar, about an inch in height and $\frac{1}{3}$ of an inch in breadth. This is bisected in the plane which passes through the obtuse angles as shown in fig. 487—that is, along the plane *abcd* (fig. 475). The two halves are then again joined in the same order by means of Canada balsam.

The principle of the Nicol's prism is this: the refractive index of Canada balsam 1·549 is less than the ordinary index of Iceland spar 1·654, but greater than its extraordinary index 1·483. Hence, when a luminous ray, SC, fig. 487, enters the prism, the ordinary ray undergoes total reflection on the surface *ab*, and takes the direction C*d*O, by which it is refracted out of the crystal; while the extraordinary ray, C*e*, emerges alone. Since the Nicol's prism allows only the extraordinary ray to pass, it may be used, like a tourmaline, as an analyser or as a polariser.

Fig. 486.

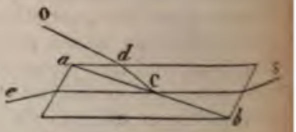


Fig. 487.

610. **Physical theory of polarised light.**—The explanation of the dark bands produced by the interference of light is stated in art. 595

esemble exactly that of the formation of nodes and loops given in rt. 251.

It might hence be supposed that the vibrations producing light are imilar to those producing sound. But this is by no means the case. n fact, if art. 601 be examined, it will be found that no assumption is ıere made as to the *direction* in which the vibrating particles move, and ccordingly that explanation is equally true whether the particles vibrate the direction AB, BA, or at right angles to AB. As a matter of fact, ıe former is the case with the vibrations producing sound, the latter ith the vibrations producing light. In other words, the vibrations pro- ıcing sound take place in the direction of propagation, the vibrations roducing light are *transversal* to the direction of propagation.

This assumption as to the direction of the vibration of the particles of her producing light is rendered necessary, and is justified by the phe- omena of polarisation.

When a ray of light is polarised, all the particles of ether in that ray ibrate in straight lines parallel to a certain direction in the front of the ave corresponding to the ray.

When a ray of light enters a double refracting medium, such as Ice- ınd spar, it becomes divided into two, as we have already seen. Now t can be shown to be in strict accordance with mechanical principles hat, if a medium possesses unequal elasticity in different directions, a plane wave produced by transversal vibrations entering that medium will give rise to two plane waves moving with different velocities within the medium, and the vibrations of the particles in front of these waves will be in directions parallel respectively to two lines at right angles to each other. If, as is assumed in the undulatory theory of light, the ether exists in a double refracting crystal in such a state of unequal elasticity, then the two plane waves will be formed as above described, and these having different velocities, will give rise to two rays of unequal refrangibility (compare art. 589). This is the physical account of the phenomenon of louble refraction. It will be remarked that the vibrations corresponding o the two rays are transversal, rectilinear, and in directions perpendicular o each other in the rays respectively. Accordingly the same theory ccounts for the fact that the two rays are both polarised, and in planes t right angles to each other.

It is a point still unsettled whether, when a ray of light is polarised ith respect to a given plane, the vibrations take place in directions ithin or perpendicular to that plane. Fresnel was of the latter opinion. t is, however, convenient in some cases to regard the plane of polarisa- on as that plane in which the vibrations take place.

OLOURS PRODUCED BY THE INTERFERENCE OF POLARISED LIGHT.

611. **Laws of the interference of polarised rays.**—After the dis- very of polarisation, Fresnel and Arago tried whether polarised rays esented the same phenomena of interference as ordinary rays. They ere thus led to the discovery of the following laws in reference to the

interference of polarised light, and, at the same time, of the brilliant phenomena of coloration, which will be presently described :—

I. When two rays polarised in the same plane interfere with each other, they will produce by their interference fringes of the very same kind as if they were common light.

II. When two rays of light are polarised at right angles to each other, they produce no coloured fringes in the same circumstances under which two rays of common light would produce them. When the rays are polarised in planes inclined to each other at any other angles, they produce fringes of intermediate brightness, and if the angle is made to change, the fringes gradually decrease in brightness from 0° to 90°, and are totally obliterated at the latter angle.

III. Two rays originally polarised in planes at right angles to each other may be subsequently brought into the same plane of polarisation without acquiring the power of forming fringes by their interference.

IV. Two rays polarised at right angles to each other, and afterwards brought into the same plane of polarisation, produce fringes by their interference like rays of common light, provided they originated in a pencil the whole of which was originally polarised in any one plane.

V. In the phenomena of interference produced by rays that have suffered double refraction, a difference of half an undulation must be allowed, as one of the pencils is retarded by that quantity from some unknown cause.

612. **Effect produced by causing a pencil of polarised rays to traverse a double refracting crystal.**—The following important experiment may be made most conveniently by Norremberg's apparatus (fig. 483). At *g* (fig. 484) there is a Nicol's prism. A plate of a double refracting crystal cut parallel to its axis is placed on the disc at *e*. In the first place, however, suppose the plate of the crystal to be removed. Then, since the Nicol's prism allows only the extraordinary ray to pass when it is turned so that its principal plane coincides with the plane of reflection, no light will be transmitted (609). Place the plate of doubly refracting crystal, which is supposed to be of moderate thickness, in the path of the reflected ray at *e*. Light is now transmitted through the Nicol's prism. On turning the plate the intensity of the transmitted light varies; it reaches its maximum when the principal plane of the plate is inclined at an angle of 45° to the plane of reflection, and disappears when these planes either coincide with or are at right angles to each other. The light in this case is white. The interposed plate may be called the *depolarising plate*. The same or equivalent phenomena are produced when any other analyser is used. Thus, assume the double refracting prism to be used. Suppose the depolarising plate to be removed. Then, generally, two rays are transmitted; but if the principal plane of the analyser is turned into the plane of primitive polarisation, the ordinary ray only is transmitted, and then, when turned through 90°, the extraordinary ray only is transmitted. Let the analyser be turned into the former position, then, when the depolarising plate is interposed, both ordinary and extraordinary rays are seen, and when the depolarising

plate is slowly turned round, the ordinary and extraordinary rays are seen to vary in intensity, the latter vanishing when the principal plane of the polarising plate either coincides with or is at right angles to the plane of primitive polarisation.

613. **Effect produced when the plate of crystal is very thin.**—In order to exhibit this, take a thin film of *selenite* or *mica* between the twentieth and sixtieth of an inch thick, and interpose it as in the last article. If the thickness of the film is uniform, the light now transmitted through the analyser will be no longer white, but of a uniform tint; the colour of the tint being different for different thicknesses—for instance, red, or green, or blue, or yellow, according to the thickness; the intensity of the colour depending on the inclination of the principal plane of the film to the plane of reflection, being greatest when the angle of inclination is 45°. Let us now suppose the crystalline film to be fixed in that position in which the light is brightest, and suppose its colour to be *red*. Let the analyser (the Nicol's prism) be turned round, the colour will grow fainter, and when it has been turned through 45°, the colour disappears, and no light is transmitted; on turning it farther, the complementary colour, *green*, makes its appearance, and increases in intensity until the analyser has been turned through 90°; after which the intensity diminishes until an angle of 135° is attained, when the light again vanishes, and, on increasing the angle, it changes again into red. Whatever be the colour proper to the plate, the same series of phenomena will be observed, the colour passing into its complementary when the analyser is turned. That the colours are really complementary is proved by using a double refracting prism as analyser. In this case two rays are transmitted, each of which goes through the same changes of colour and intensity as the single ray described above, but whatever be the colour and intensity of the one ray in a given position, the other ray will have the same when the analyser has been turned through an angle of 90°. Consequently, these two rays give simultaneously the appearances which are successively presented in the above case by the same ray at an interval of 90°. If now the two rays are allowed to overlap, they produce white light; thereby proving their colours to be complementary.

Instead of using plates of different thickness to produce different tints, the same plate may be employed inclined at different angles to the polarised ray. This causes the ray to traverse the film obliquely, and, in fact, amounts to an alteration in its thickness.

With the same substance, but with plates of increasing thickness, the tints follow the laws of the colours of Newton's rings (609). The thickness of the depolarising plate must, however, be different from that of the layer of air in the case of Newton's rings to produce corresponding colours. Thus corresponding colours are produced by a plate of mica and a layer of air when the thickness of the former is about 400 times that of the latter. In the case of selenite the thickness is about 230 times, and in the case of Iceland spar about 13 times, that of the corresponding layer of air.

614. **Theory of the phenomena of depolarisation.**—The phen
described in the last articles admit of complete explanation by the
latory theory, but not without the aid of abstruse mathematical c
tions. What follows will show the nature of the explanation.
suppose, for convenience, that in the case of a polarised ray the p
of ether vibrate in the plane of polarisation (see art. 610), and t
analyser is a double refracting prism, with its principal plane in th
of primitive polarisation; then the vibrations being wholly in tha
have no resolved part in a plane at right angles to it, and, conseq
no extraordinary ray passes through the analyser; in other word
an ordinary ray passes. Now take the depolarising plate cut par
the axis, and let it be interposed in such a manner that its principa
makes any angle (θ) with the plane of primitive polarisation. Th
of this will be to cause the vibrations of the primitive ray to be r
in the principal plane, and at right angles to the principal plane, t
giving rise to an ordinary ray (O), and an extraordinary ray (E),
however, do not become separated on account of the thinness of t
polarising plate. They will not form a single plane polarised
leaving the plate, since they are unequally retarded in passing thr
and consequently leave it in different phases. Since neither of the
of polarisation of O and E coincides with the principal plane
analyser, the vibrations composing them will again be resolved
analyser into vibrations in and at right angles to the principal plan
O gives rise to O*o* and O*e*, and E gives rise to E*o* and E*e*. I
vibrations composing O*o* and E*o* being in the same plane give r
single ordinary ray, I*o*, and in like manner O*e* and E*e* give rise to a
extraordinary ray, I*e*. Thus the interposition of the depolarising
restores the extraordinary ray.

Suppose the angle θ to be either 0° or 90°. In either case the vib
are transmitted through the depolarising plate without resolution,
quently they remain wholly in the plane of primitive polarisation,
entering the analyser cannot give rise to an extraordinary ray.

If the Nicol's prism is used as an analyser, the ordinary ray
pressed by mechanical means. Consequently only I*e* will pass t
the prism, and that for all values of θ except 0° and 90°.

A little consideration will show that the joint intensities of all t
existing at any stage of the above transformations must continue c
but that the intensities of the individual rays will depend on the ma
of θ, and when this circumstance is examined in detail, it expla
fact that I*e* increases in intensity as θ increases from 0° to 45°, a
decreases in intensity as θ increases from 45° to 90°.

In regard to the colour of the rays, it is to be observed that the f
for the intensities of I*o* and I*e* contain a term depending on the le
the wave and the thickness of the plate. Consequently, when whi
is used, the relative intensities of its component colours are chang
therefore, I*o* and I*e* will each have a prevailing tint, which will be d
for different thicknesses of the plate. The tints will, however, be c
mentary, since, the joint intensities of I*o* and I*e* being the same as

e original ray, they will, when superimposed, restore all the components that ray in their original intensities, and therefore produce white light.

615. **Coloured rings produced by polarised light in traversing uble refracting films.**—In the experiments with Norremberg's appa- tus which have just been described (605), a pencil of parallel rays

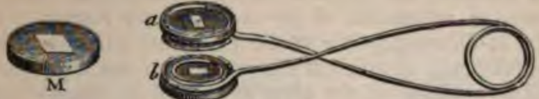


Fig. 488.

iverses the film of crystal perpendicularly to its faces, and as all parts the film act in the same manner, there is everywhere the same tint. ut when the incident rays traverse the plate under different obliquities, hich comes to the same thing as if they traversed plates differing in ickness, coloured rings are formed similar to Newton's rings.

The best method of observing these new phenomena is by means of e *tourmaline pincette*. This is a small instrument consisting of two urmalines, cut parallel to the axis, each of them being fitted in a copper isc. These two discs, which are perforated in the centre, and blackened, e mounted in two rings of silvered copper, which is coiled, as shown in e figure, so as to form a spring, and press together the tourmalines. he tourmalines turn with the disc, and may be so arranged that their es are either perpendicular or parallel.

The crystal to be experimented upon being fixed in the centre of a cork sc, is placed between the two tourmalines, and the pincette is held before e eye so as to view diffused light. The tourmaline farthest from the eye ts as polariser, and the other as analyser. If the crystal thus viewed is iaxial, and cut perpendicularly to the axis, and a homogeneous light— d, for instance—is looked at, a series of alternately dark and red rings e seen. With another simple colour similar rings are obtained, but eir diameter decreases with the refrangibility of the colour. On the her hand, the diameters of the rings diminish when the thickness of the ates increases, and beyond a certain thickness no more rings are pro- ced. If, instead of illuminating the rings by homogeneous light, white ht be used, as the rings of the different colours produced have not the ne diameter, they are partially superposed, and produce very brilliant iegated colours.

The position of the crystal has no influence on the rings, but this is not case with the relative position of the two tourmalines. For instance, experimenting on Iceland spar cut perpendicular to the axis, and from 20 millimeters in thickness, when the axes of the tourmalines are pendicular, a beautiful series of rings is seen brilliantly coloured, and ersed by a black cross, as shown in fig. 1, Plate II. If the axes of tourmalines are parallel, the rings have tints complementary to those had at first, and there is a white cross (fig. 11, Plate II.), instead of a k one.

In order to understand the formation of these rings when polarised light traverses double refracting films, it must first be premised that these films are traversed by a converging conical pencil, whose summit is the eye of the observer. Hence it follows that the virtual thickness of the film which the rays traverse increases with their divergence ; but for rays of the same obliquity this thickness is the same : hence there result different degrees of retardation of the ordinary with respect to the extraordinary ray at different points of the plate, and consequently different colours are produced at different distances from the axis, but the same colours will be produced at the same distance from the axis, and consequently the colours are arranged in circles round the axis. The arms of the black cross are parallel to the optic axis of each of the tourmalines, and are due to an absorption of the polarised light in these directions. When the tourmalines are parallel the vibrations are transmitted, and hence the white cross.

Analogous effects are produced with all uniaxial crystals ; for instance, tourmaline, emerald, sapphire, beryl, mica, pyromorphite, and ferrocyanide of potassium.

616. **Rings in biaxial crystals.**—In biaxial crystals, coloured rings are also produced, but their form is more complicated. The coloured bands, instead of being circular and concentric, have the form of curves, with two centres, the centre of each system corresponding to an axis of the crystal. Figs. 4, 5, and 6, Plate II., represent the curves seen when a plate of either Cerussite or carbonate of lead, topaz, or nitre, cut perpendicularly to the axis, is placed between the two tourmalines, the plane containing the axis of the crystal being in the plane of primitive polarisation. When the axes of the two tourmalines are at right angles to each other, fig. 4, Plate II. is obtained. On turning the crystal without altering the tourmalines, fig. 5, Plate II. is seen, which changes into fig. 6, Plate II. when the crystal has been turned through 45°. If the axes of the tourmalines are parallel, the same coloured curves are obtained, but the colours are complementary, and the black cross changes into white. The angle of the optic axis in the case of nitre is only 5° 20′, and hence the whole system can be seen at once. But when the angle exceeds 20 to 25°, the two systems of curves cannot be simultaneously seen. There is then only one dark bar instead of the cross, and the bands are not oval, but circular. Fig. 3, Plate II. represents the phenomenon as seen with arragonite.

Herschel, who has carefully measured the rings produced by biaxial crystals, refers them to the kind of curve known in geometry as the *lemniscate*, in strict accordance with the results of the undulatory theory of light.

The observation of the system of rings which plates of crystals give in polarised light presents a means of distinguishing between optical uniaxial and optical biaxial crystals, even in cases in which no conclusion can be drawn as to the system in which a mineral crystallises from mere morphological reasons. In this way, the optical investigation becomes a valuable aid in mineralogy, as, for example, in the case of mica, of which there are two mineralogical species, the uniaxial and the biaxial.

e phenomena which have been described are only obtained by f polarised light. Hence a double refracting film, with either a prism or a tourmaline as analyser, may be used to distinguish be- olarised and unpolarised light—that is, as a polariscope.

Colours produced by compressed or by unannealed glass.— y glass is not endowed with the power of double refraction. It

Fig. 489.

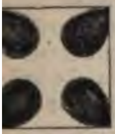


Fig. 490.

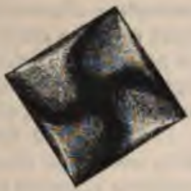
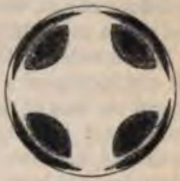


Fig. 491.



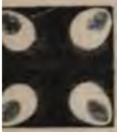


Fig. 492.

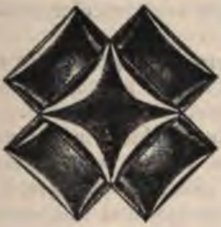


Fig. 493.

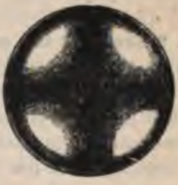


Fig. 494.

this property, however, if by any cause its elasticity becomes dified in one direction than in another. In order to effect this, e strongly compressed in a given direction, or it may be curved, ered—that is to say, cooled after having been heated. If the hen traversed by a beam of polarised light, effects of colour are which are entirely analogous to those described in the case y refracting crystals. They are, however, susceptible of far ariety, according as the plates of glass have a circular, square, lar, or triangular shape, and according to the degree of tension articles.

the polariser is a mirror of black glass, on which the light of the cident, and the analyser is a Nicol's prism, through which the tes traversed by polarised light are viewed, figs. 489, 490, 492, the appearances presented successively, when a square plate ressed glass is turned in its own plane; figs. 491 and 494 re- the appearances produced by a circular plate under the same ances; and fig. 493, that produced when one rectangular plate is ed on another. This figure also varies when the system of plates .

ressed and curved glasses present phenomena of the same kind, so vary under the same conditions.

ELLIPTICAL, CIRCULAR, AND ROTATORY POLARISATION.

618. **Definition of elliptical and circular polarisation.**—In the cases hitherto considered the particles of ether composing a polarised ray vibrate in parallel straight lines; to distinguish this case from those we are now to consider such light is frequently called *plain polarised light*. It sometimes happens that the particles of ether describe *ellipses* round their positions of rest, the planes of the ellipses being perpendicular to the direction of the ray. If the axes of these ellipses are equal and parallel, the ray is said to be *elliptically polarised*. In this case the particles which, when at rest, occupied a straight line, are, when in motion, arranged in a helix round the line of their original position as an axis, the helix changing from instant to instant. If the axes of the ellipses are equal, they become circles, and the light is said to be *circularly polarised*. If the minor axes become zero, the ellipses coincide with their major axes, and the light becomes *plane polarised*. Consequently, *plane* polarised light and *circularly* polarised light are particular cases of elliptically polarised light.

619. **Theory of the origin of elliptical and circular polarisation.**—Let us in the first place consider a simple pendulum (51) vibrating in any plane, the arc of vibration being small. Suppose that, when in its lowest position, it received a blow in a direction at right angles to the direction of its motion, such as would make it vibrate in an arc at right angles to its arc of primitive vibration, it follows from the law of the composition of velocities (48) that the joint effect will be to make it vibrate in an arc inclined at a certain angle to the arc of primitive vibration, the magnitude of the angle depending on the magnitude of the blow. If the blow communicated a velocity equal to that with which the body is already moving, the angle would be 45°. Next suppose the blow to communicate an equal velocity, but to be struck when the body is at its highest point, this will cause the particle to describe a circle, and to move as a conical pendulum (53). If the blow is struck under any other circumstances, the particle will describe an ellipse. Now as the two blows would produce separately two simple vibrations in directions at right angles to each other, we may state the result arrived at as follows:—If two rectilinear vibrations are superinduced on the same particle in directions at right angles to each other, then: 1. If they are in the same or opposite phases, they make the point describe a rectilinear vibration in a direction inclined at a certain angle to either of the original vibrations. 2. But if their phases differ by 90° or a quarter of a vibration, the particle will describe a circle, provided the vibrations are equal. 3. Under other circumstances the particle will describe an ellipse.

To apply this to the case of polarised light. Suppose two rays of light polarised in perpendicular planes to coincide, each would separately cause the same particles to vibrate in perpendicular directions. Consequently—1. If the vibrations are in the same or opposite phases, the

ting from the two rays is plane polarised. 2. If the rays are
ntensity, and their phases differ by 90°, the resulting light is
polarised. 3. Under other circumstances the light is ellipti-
rised.
example, if reference is made to arts. 612 and 613, it will be
the rays denoted by O and E are superimposed in the manner
cribed. Consequently, the light which leaves the depolarising
lliptically polarised. If, however, the principal plane of the
ng plate is turned so as to make an angle of 45° with the plane
e polarisation, O and E have equal intensities; and, if further,
is made of a certain thickness, so that the phases of O and E
by 90°, or by a quarter of a vibration, the light which emerges
late is circularly polarised. This method may be employed to
ircularly polarised light.
r or elliptical polarisation may be either *right-handed* or *left-*
what is sometimes called *dextrogyrate* and *lævogyrate*. If the
looks along the ray in the direction of propagation, from polar-
alyser, then, if the particles move in the same direction as the
watch, with its face to the observer, the polarisation is right-

esnel's rhomb.—This is a means of obtaining circularly
light. We have already seen (619) that, to obtain a ray of
polarised light, it is sufficient to decompose a ray of plane
light in such a manner as to produce two rays of light of equal
polarised in planes at right angles to each other, and differing
ths by a quarter of an undulation. Fresnel effected this by
a rhomb, which has received his name. It is made of glass;
ngle is 54°, and its obtuse 126°. If a ray, *a*, fig. 495, of plane 30
light falls perpendicularly on the face AB, it will undergo two
nal reflections at an angle of about 54°, one at E, and the other
will emerge perpendicularly.
plane ABCD be inclined at an angle of 45° to the plane of
n, the polarised ray will be divided into two coincident rays,
planes of polarisation at right angles
her, and it appears that one of them
tly a quarter of an undulation, so that
ng from the rhomb the ray is circu-
rised. If the ray emerging as above
snel's rhomb is examined, it will be
iffer from plane polarised light in this,
it passes through a double refracting
ordinary and extraordinary rays are
tensity in all positions of the prism.
it differs from ordinary light in this,
assed through a second rhomb placed
the first, a second quarter of an
will be lost, so that the parts of the
lane polarised ray will differ by half an undulation, and the

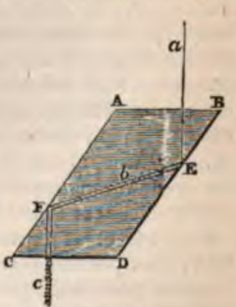


Fig. 495.

emergent ray will be plane polarised; moreover, the plane of polarisation will be inclined at an angle of 45° to ABCD, but on the *other side* from the plane of primitive polarisation.

621. **Elliptical polarisation.**—Our limits will not allow us to enter into this subject, but we may state that, in addition to the method already mentioned (620), elliptically polarised light is generally obtained whenever plane polarised light suffers reflection. Polarised light reflected from metals becomes elliptically polarised, the degree of ellipticity depending on the direction of the incident ray, and of its plane of polarisation, as well as on the reflecting substance. When reflected from silver, the polarisation is almost circular, and from galena almost plane. If elliptically polarised light be analysed by the Nicol's prism, it never vanishes, though at alternate positions it becomes fainter; it is thus distinguished from plane and from circular polarised light. If analysed by Iceland spar neither image disappears, but they undergo changes in intensity.

Light can also be polarised elliptically in Fresnel's rhomb. If the angle between the planes of primitive polarisation and of incidence be any other than 45°, the emergent ray is elliptically polarised.

622. **Rotatory polarisation.**—Rock crystal or quartz possesses a remarkable property which was long regarded as peculiar to itself among all crystals, though it has been since found to be shared by tartaric acid and its salts, together with some other crystalline bodies. This property is called rotatory polarisation, and may be described as follows:—Let a ray of homogeneous light (for example, red light) be polarised, and let the analyser, say a Nicol's prism, be turned till the light does not pass through it. Take a thin section of a quartz crystal cut at right angles to its axis, and place it between the polariser and the analyser with its plane at right angles to the rays. The light will now pass through the analyser. The phenomenon is not the same as that previously described (612), for, if the rock crystal is turned round its axis, no effect is produced, and if the analyser is turned, the ray is found to be *plane polarised*, in a plane inclined at a certain angle to the plane of primitive polarisation. If the light is red, and the plate 1 millimeter thick, this angle is about 17°. In some specimens of quartz the plane of polarisation is turned to the right hand, in others to the left hand. Specimens of the former kind are said to be right-handed, those of the latter kind left-handed. This difference corresponds to a difference in crystallographic structure. The property possessed by rock crystal of turning the plane of polarisation through a certain angle was thoroughly investigated by M. Biot, who, amongst other results, arrived at this:—For a given colour the angle through which the plane of polarisation is turned is proportional to the thickness of the quartz.

623. **Physical explanation of rotatory polarisation.**—The explanation of the phenomenon described in the last article is as follows:—When a ray of polarised light passes along the axis of the quartz crystal, it is divided into two rays of *circularly* polarised light of equal intensity, which pass through the crystal with different velocities. In one the circular polarisation is right-handed, in the other left-handed (619). The existence

f these rays was proved by Fresnel, who succeeded in separating them. n emerging from the crystal, they are compounded into a plane polarised y, but since they move with unequal velocities within the crystal, they merge in different phases, and consequently the plane of polarisation ill not coincide with the plane of primitive polarisation. This can be adily shown by reasoning similar to that employed in art. 619. The me reasoning will also show that the plane of polarisation will be rned to the right or left, according as the right-handed or left-handed y moves with the greater velocity. Moreover, the amount of the rotation ll depend on the amount of the retardation of the ray whose velocity is st—that is to say, it will depend on the thickness of the plate of quartz. this manner the phenomena of rotatory polarisation can be completely counted for.

624. **Coloration produced by rotatory polarisation.**—The rotation different with different colours ; its magnitude depends on the re- ngibility, and is greatest with the most refrangible rays. In the case red light a plate 1 millimeter in thickness will rotate the plane 17°, ile a plate of the same thickness will rotate it 44° in the case of violet ht. Hence with white light there will, in each position of the analysing col's prism, be a greater or less quantity of each colour transmitted. the case of a right-handed crystal, when the Nicol's prism is turned to right, the colours will successively appear from the less refrangible to more so—that is, in the order of the spectrum, m red to violet; with a left-handed crystal in reverse order. Obviously in turning the Nicol's sm to the left, the reverse of these results will e place.

Fig. 496.

When a quartz plate cut perpendicularly to the s and traversed by a ray of polarised light is ked at through a doubly refracting prism, two brilliantly coloured images seen, of which the tints are complementary; for their images are partially erposed, and in this position there is a white light (fig. 496). When the sm is turned from left to right, the two images change colours, and as- ne successively all the colours of the spectrum.

This will be understood from what has been said about the different ation for different colours. Quartz rotates the plane of polarisation for 17° for each millimeter, and for violet 44°; hence from the great ference of these two angles, when the polarised light which has traversed quartz plate emerges, the various simple colours which it contains are larised in different planes. Consequently, when the rays thus trans- tted by the quartz pass through a double refracting prism, they are h decomposed into two others polarised at right angles to each other : various simple colours are not divided in the same proportion be- een the ordinary and extraordinary rays furnished by the prism ; the images are, therefore, coloured ; but, since those which are wanting in one occur in the other, the colours of the images are perfectly com- mentary.

These phenomena of coloration may be well seen by means of Norremberg's apparatus (fig. 483). A quartz plate, *s*, cut at right angles to the axis and fixed in a cork disc, is placed on the screen, *e*; the mirror, *n* (fig. 483), being then so inclined that a ray of polarised light passes through the quartz, the latter is viewed through a refracting prism, *g*; when this tube is turned, the complementary images furnished by the passage of polarised light through the quartz are seen.

625. **Rotatory power of liquids.**—Biot has found that a great number of liquids and solutions possess the property of rotatory polarisation.

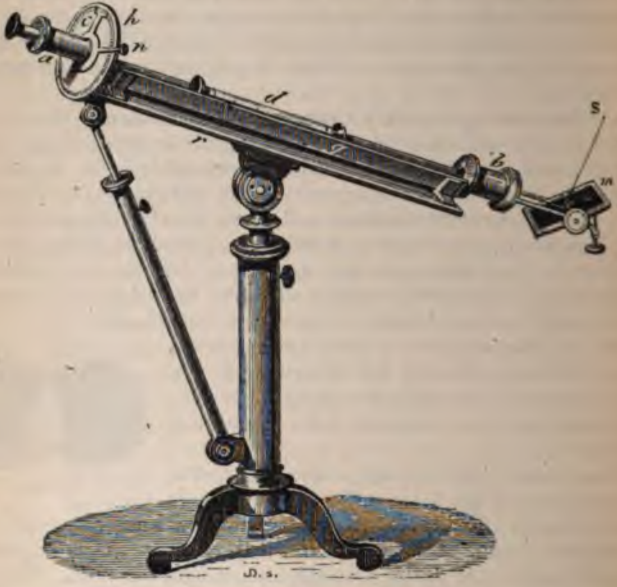


Fig. 497.

He has further observed that the deviation of the plane of polarisation can reveal differences in the composition of bodies where none is exhibited by chemical analysis. For instance, uncrystallisable grape-sugar deflects the plane of polarisation to the left, while cane-sugar deflects it to the right, although the chemical composition of the two sugars is the same.

The rotatory power of liquids is far less than that of quartz. In concentrated syrup of cane-sugar, which possesses the rotatory power in the highest degree, the power is $\frac{1}{36}$th that of quartz, so that it is necessary to operate upon columns of liquids of considerable length—8 inches for example.

Fig. 497 represents the apparatus devised by Biot for measuring the rotatory power of liquids. On a metal groove, *g*, fixed to a support, *r*, is a brass tube 20 centimeters long, in which is contained the liquid expeited upon. This tube, which is tinned inside, is closed at each end by plates fastened by screw collars. At *m* is a mirror of black glass, in-l at the polarising angle to the axis of the tubes *bd* and *a*, so that the eflected by the mirror *m*, in the direction *bda*, is polarised. In the e of the graduated circle *h*, inside the tube *a*, and at right angles to xis *bda*, is a double refracting achromatic prism, which can be turned the axis of the apparatus by means of a button, *n*. The latter is to a limb, *c*, on which is a vernier, to indicate the number of degrees d through. Lastly, from the position of the mirror *m*, the plane of isation, S*od*, of the reflected ray is vertical, and the zero of the ation on the circle, *h*, is on this plane.

fore placing the tube *d* in the groove *g*, the extraordinary image fur-d by the double refracting prism disappears whenever the limb *c* cor-nds to the zero of the graduation, because then the double refracting is so turned that its principal section coincides with the plane of sation (610). This is the case also when the tube *d* is full of water y other *inactive* liquid, like alcohol, ether, etc., which shows that the of polarisation has not been turned. But if the tube be filled with tion of cane-sugar or any other *active* liquid, the extraordinary image ears, and to extinguish it the limb must be turned to a certain extent to the right or to the left of zero, according as the liquid is right-ed or left-handed, showing that the polarising plane has been turned e same angle. With solution of cane-sugar the rotation takes place right; and if with the same solution tubes of different lengths are , the rotation is found to increase proportionally to the length, in con-ty with art. 622; further, with the same tube, but with solutions of is strength, the rotation increases with the quantity of sugar dis-l, so that the quantitative analysis of a solution may be made by s of its angle of deviation.

this experiment homogeneous light must be used; for, as the various of the spectra have different rotatory powers, white light is decom-in traversing an active liquid, and the extraordinary image does not pear completely in any position of the double refracting prism—it y changes the tint. The transition tint (626) may, however, be ob-d. To avoid this inconvenience, a piece of red glass is placed in the between the eye and the double refracting prism, which only allows ght to pass. The extraordinary image disappears in that case, when-the principal section of the prism coincides with the plane of polari-n of the red ray.

. **Soleil's saccharimeter.**—M. Soleil has constructed an apparatus, l upon the rotatory power of liquids, for analysing saccharine sub-es, to which the name *saccharimeter* is applied.

gure 498 represents the saccharimeter fixed horizontally on its foot, ig. 499 gives a longitudinal section, with the modifications which have introduced by M. Duboscq.

e principle of this instrument is not the amplitude of the rotation of lane of polarisation, as in Biot's apparatus, but that of *compensation*; s to say, a second active substance is used acting in the opposite direction to that analysed, and whose thickness can be altered contrary actions of the two substances completely neutralise ea Instead of measuring the deviation of the plane of polarisation, t ness is measured which the plate of quartz must have in order perfect compensation.

The apparatus consists of three parts—a tube containing the be analysed, a polariser, and an analyser.

The tube *m*, containing the liquid, is made of copper, tinned c side, and closed at both ends by two glass plates. It rests on a *k*, terminated at both ends by tubes, *r* and *a*, in which are the used as analysers and polarisers, and which are represented i (fig. 499).

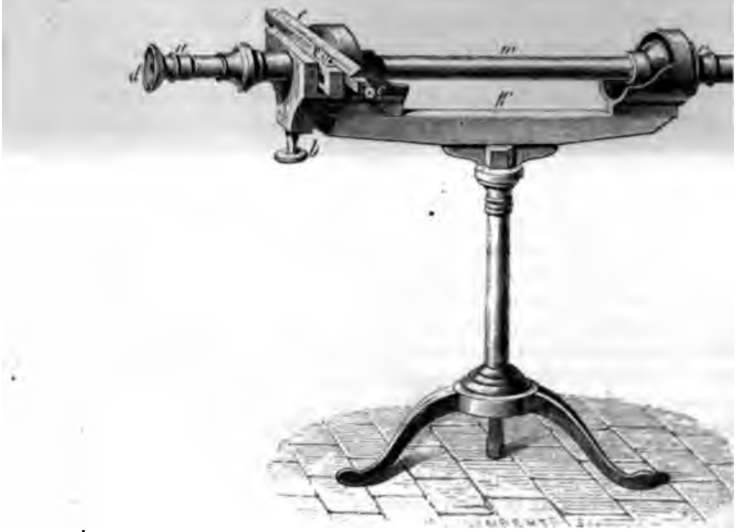
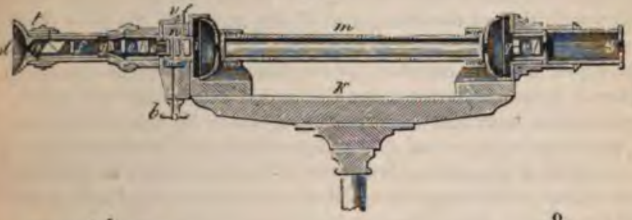


Fig. 498.

In front of the aperture, S (fig. 499), is placed an ordinary m lamp. The light emitted by this lamp in the direction of the a meets a double refracting prism, *r*, which serves as polariser (607 ordinary image alone meets the eye, the extraordinary image bei jected out of the field of vision in consequence of the amplitud angle which the ordinary makes with the extraordinary ray. The refracting prism is in such a position that the plane of polaris vertical, and passes through the axis of the apparatus.

Emerging from the double refracting prism, the polarised ray plate of quartz with double rotation ; that is, this plate rotates th both to the right and to the left. This is effected by constructing th of two quartz plates of opposite rotation placed one on the other, as in figure 502, so that the line of separation is vertical and in the same plane as the axis of the apparatus. These plates, cut perpendicularly to the axis, have a thickness of 3·75 millimeters, corresponding to a rotation of 90°, and give a rose-violet tint, called the ***tint of passage*** or ***transition-tint.*** As the quartz, whether right-handed or left-handed, turns always to the same extent for the same thickness, it follows that the two quartz plates, *a* and *b*, turn the plane of polarisation equally, one to the right and

Fig. 499.



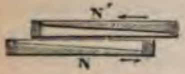


Fig. 500.

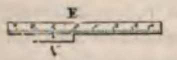


Fig. 501.

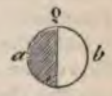


Fig. 502.

he other to the left. Hence, looked at through a double refracting prism, hey present exactly the same tint.

Having traversed the quartz, *q*, the polarised ray passes into the liquid n the tube *m*, and then meets a single plate of quartz, *i*, of any thickness, he use of which will be seen presently. The compensator, *n*, which de-troys the rotation of the column of liquid *m*, consists of two quartz plates, ith the same rotation either to the right or the left, but opposite to that f the plate *i*. These two quartz plates, a section of which is represented n fig. 500, are obtained by cutting obliquely a quartz plate with parallel ides, so as to form two prisms of the same angle, N, N′; superposing, then, hese two prisms, as shown in the figure, a single plate is obtained with arallel faces, which can be varied at will. This is effected by fixing each rism to a slide, so as to move it in either direction without disturbing the arallelism. This motion is effected by means of a double rackwork and inion motion turned by a milled head, *b* (figs. 498, 499).

When these plates move in the direction indicated by the arrows ig. 500), it is clear that the sum of their thicknesses increases, and that diminishes when the plates are moved in the contrary direction. A cale and a vernier follow the plates in their motion, and measure the hickness of the compensator. This scale, represented with its vernier n figure 501, has two divisions, with a common zero, one from left to ight for right-handed liquids, and another from right to left for left-anded.

When the vernier is at zero of the scale, the sum of the thicknesses of he plates NN′ is exactly equal to that of the plate *i*, and as the rotation of the latter is opposed to that of the compensator, the effect is zero. But by moving the plates of the compensator in one or the other direction, either the compensator or the quartz, *i*, preponderates, and there is a rotation from left to right.

Behind the compensator is a double refracting prism, *c* (fig. 499), serving as analyser to observe the polarised ray which has traversed the liquid and the various quartz plates. In order to understand more easily the object of the prism, *c*, we will neglect for a moment the crystals and the lenses on the left of the drawing. If at first the zero of the vernier, *e*, coincides with that of the scale, and if the liquid in the tube is inactive, the actions of the compensator, and of the plate *i*, neutralise each other; and the liquid having no action, the two halves of the plate *q*, seen through the prism *c*, give exactly the same tint as has been observed above. But if the tube filled with inactive liquid be replaced by one full of solution of sugar, the rotatory power of this solution is added to that of one of the halves (*a* or *b*) of the plate *q* (viz. that half which tends to turn the plane of polarisation in the same direction as the solution), and subtracted from that of the other. Hence the two halves of the plate *q* no longer show the same tint; the half *a*, for instance, is red, while the half *b* is blue. The prisms of the compensator are then moved, by turning the milled head *b*, either to the right or to the left, until the difference of action of the compensator and of the plate *i* compensates the rotatory power of the solution, which takes place when the two halves of the plate Q, with double rotation, revert to their original tint.

The direction of the deviation and the thickness of the compensator are measured by the relative displacement of the scale *e*, and of the vernier *r*. Ten of the divisions on the scale correspond to a difference of 1 millimeter in the thickness of the compensator; and as the vernier gives itself tenths of these divisions, it therefore measures differences of $\frac{1}{100}$ in the thickness of the compensator.

When once the tints of the two halves of the plate are exactly the same, and therefore the same as before interposing the solution of sugar, the division on the scale corresponding to the vernier is read off, and the corresponding number gives the strength of the solution. This depends on the principle that 16·471 grains of pure and well-dried sugar-candy being dissolved in water, and the solution diluted to the volume of 100 cubic centimeters, and observed in a tube of 20 centimeters in length, the deviation produced is the same as that effected by a quartz plate a millimeter thick. In making the analysis of raw sugar, a normal weight of 16·471 grains of sugar is taken, dissolved in water, and the solution made up to 100 cubic centimeters, with which a tube 20 centimeters in length is filled, and the number indicated by the vernier read off, when the primitive tint has been obtained. This number being 42, for example, it is concluded that the amount of crystallisable sugar in the solution is 42 per cent. of that which the solution of sugar-candy contained, and, therefore, 16·471 grains × $\frac{42}{100}$ or 6·918 grains. This result is only valid when the sugar is not mixed with uncrystallisable sugar or some other left-handed substance. In that case the crystallisable sugar, which is right-handed, ust be, by means of hydrochloric acid, converted into uncrystallisable gar, which is left-handed ; and a new determination is made, which, gether with the first, gives the quantity of crystallisable sugar.

The arrangement of crystals and lenses, o, g, f, and a, placed behind e prism c, forms what M. Soleil calls the *producer of sensible tints.* or the most delicate tint, that by which a very feeble difference in the loration of the two halves of the rotation plate can be distinguished, is t the same for all eyes ; for most people it is of a violet blue tint, like x-blossom, and it is important either to produce this tint or some other ually sensible to the eye of the observer. This is effected by placing front of the prism c, at first a quartz plate, o, cut perpendicular to the is, then a small Galilean telescope consisting of a double convex glass, and a double concave glass, f, which can be approximated or removed m each other according to the distance of distinct vision of each ob-rver. Lastly, there is a double refracting prism, c, acting as polariser reference to the quartz, and the prism a as analyser ; and hence, when e latter is turned either right or left, the light which has traversed the ism c, and the plate o, changes its tint, and finally gives that which is e most delicate for the experimenter.

627. **Analysis of diabetic urine.**—In the disease *diabetes*, the urine ntains a large quantity of fermentescible sugar, called diabetic sugar, ich in the natural condition of the urine turns the plane of polarisation the right. To estimate the quantity of this sugar, the urine is first rified by heating it with acetate of lead and filtering ; the tube is filled th the clear liquid thus obtained ; and the milled head, b, turned, until means of the double rotating plate the same tint is obtained as before e interposition of the urine. Experiment has shown that 100 parts of e saccharimetric scale represent the displacement which the quartz mpensators must have when there are 225·6 grains of sugar in a litre ; nce each division of the scale represents 2·256 of sugar. Accordingly, obtain the quantity of sugar in a given urine, the number indicated by e vernier at the moment at which the primitive tint reappears must be ltiplied by 2·256.

628. **Polarisation of heat.**—The rays of heat, like those of light, may come polarised by reflection and by refraction. The experiments on s subject are difficult of execution ; they were first made by Malus and rard, in 1810 ; after the death of Malus they were continued by the ter philosopher.

In his experiments, the calorific rays reflected from one mirror were eived upon a second, just as in Norremberg's apparatus ; from the second y fell upon a small metallic reflector, which concentrated them upon bulb of a differential thermometer. Berard observed that heat was reflected when the plane of reflection of the second mirror was at ht angles to that of the first. As this phenomenon is the same as that sented by light under the same circumstances, Berard concluded that at became polarised in being reflected.

The double refraction of heat may be shown by concentrating the sun's s by means of a heliostate on a prism of Iceland spar, and investigating

the resultant pencil by means of a thermopile, which must have
narrow edge. In this case also there is an ordinary and an extrao
ray, which follows the same laws as those of light. In the optic
the calcspar, heat is not doubly refractive. A Nicol's prism can
for the polarisation of heat as well as for that of light : a polari
does not traverse the second Nicol if the plane of its principal se
perpendicular to the vibrations of the ray. The phenomena of th
isation of heat may also be studied by means of plates of tou
and of mica. The angle of polarisation is virtually the same for
for light. In all these experiments the prisms must be very ne
other.

The diffraction, and therefore the interference, of rays of h
recently been established by the experiments of Knoblauch and
And Forbes, who has repeated Fresnel's experiment with a rhomb
of rock salt, has found that heat by two total internal reflections i
larly polarised just as is the case with light.

BOOK VIII.

ON MAGNETISM.

CHAPTER I.

PROPERTIES OF MAGNETS.

Natural and artificial magnets.—*Magnets* are substances which he property of attracting iron, and the term *magnetism* is applied cause of this attraction, and to the resulting phenomena.

s property was known to the ancients; it exists in the highest e in an ore of iron which is known in chemistry as the magnetic of iron. Its composition is represented by the formula $Fe_3\ O_4$. s magnetic oxide of iron, or *lodestone*, as it is called, was first found gnesia, in Asia Minor, the name magnet being derived from this nstance. The name lodestone, which is applied to this natural et, was given on account of its being used when suspended as a g or leading stone, from the Saxon *lædan*, to lead; so also the word ar. Lodestone is very abundant in nature: it is met with in the geological formations, especially in Sweden and Norway, where it ked as an iron ore, and furnishes the best quality of iron.

en a bar or needle of steel is rubbed with a magnet, it acquires etic properties. Such bars are called *artificial magnets*; they are powerful than natural magnets, and as they are also more connt, they will be exclusively referred to in describing the phenomena gnetism; the best modes of preparing them will be explained in a quent article.

. **Poles and neutral line.**—When a small particle of soft iron is nded by a thread, and a magnet is approached to it, the iron is ted towards the magnet, and some force is required for its removal. force of the attraction varies in different parts of the magnet: it is gest at the two ends, and is totally wanting in the middle.

is variation may also be seen very clearly when a magnetic bar is d in iron filings: these become arranged round the ends of the bar thery tufts, which decrease towards the middle of the bar, where are none. That part of the surface of the bar where there is no e magnetic force is called the *neutral line*; and the points near the of the bar where the attraction is greatest are called the *poles*. magnet, whether natural or artificial, has two poles and a neutral line : sometimes, however, in magnetising bars and needles, produced lying between the extreme points. Such magnets are and these points are called *intermédiate* or *consequent poles.* Th line joining the two poles is termed the *axis* of the magnet ; ir shoe magnet the axis is in the direction of the keeper. The right angles to the axis of a bar magnet and passing through tl line is sometimes called the *equator* of the magnet.

We shall presently see that a freely suspended magnet al with one pole pointing towards the north, and the other to

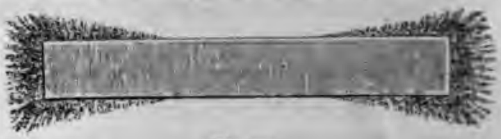


Fig. 503.

south. The end pointing towards the north is called in this co *north pole*, and the other end is the *south pole.* The end of the needle pointing to the north is also sometimes called the *mark* the needle.

631. **Mutual action of two poles.**—The two poles of a magn identical when they are br contact with iron filings, identity is only apparent. Fo small magnetic needle, *ab* (fig suspended by a fine thread, north pole, A, of another r brought near its north pole, *a*, sion takes place. If, on the A is brought near the south p the moveable needle, the strongly attracted. Hence tl poles, *a* and *b*, are not iden one is repelled and the other by the same pole of the ma It may be shown in the same that the two poles of the latter different, by successively pr them to the same pole, *a*, of the moveable needle. In one case repulsion, in the other attraction. Hence the following law enunciated :

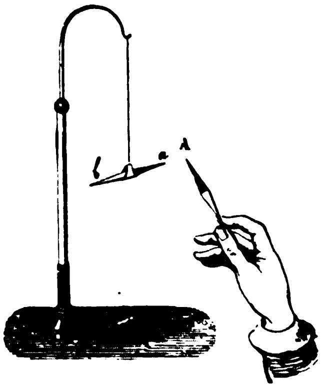


Fig. 504.

Poles of the same name repel, and poles of contrary name att another.

The opposite actions of the north and south poles may be s the following experiment :—A piece of iron, a key for example ported by a magnetised bar. A second magnetised bar of t dimensions is then moved along the first, so that their poles are (fig. 505). The key remains suspended so long as the two pol distance, but when they are sufficiently near, the key drops, just as bar which supported it had lost its magnetism. This, however, is

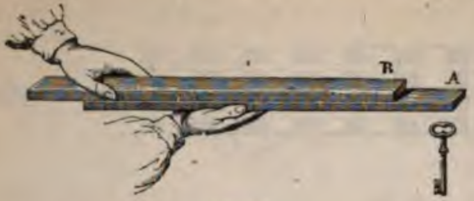


Fig. 505.

[illegible]

ie case, for the key would be again supported if the first magnet were nted to it after the removal of the second bar.

e attraction which a magnet exerts upon iron is reciprocal, which is d a general principle of all attractions. It is easily verified by pre-g a mass of iron to a moveable magnet, when the latter is attracted.

. **Hypothesis of two magnetic fluids.**—In order to explain the mena of magnetism, the existence of two hypothetical *magnetic* has been assumed, each of which acts repulsively on itself, but ts the other fluid. The fluid predominating at the north pole of the et is called the *north* fluid, and that at the south pole, the *south* The term 'fluid' is apt to puzzle beginners, from its ambiguity. arily the idea of a liquid is associated with a fluid; hence the use of erm to explain the phenomena of magnetism and electricity has ced a widely prevailing impression of the material nature of these rces. The word fluid, it must be remembered, embraces gases as s liquids, and here it must be pictured to the mind as representing visible, elastic, gaseous atmosphere or shell surrounding the particles magnetic substances.

is assumed that, before magnetisation, these fluids are combined each molecule, and mutually neutralise each other; they can be ated by the influence of a force greater than that of their mutual tion, and can arrange themselves round the molecules to which they ttached, but cannot be removed from them. [illegible]

e hypothesis of the two fluids is very convenient in explaining mag-phenomena, and will be adhered to in what follows. But it must not garded as anything more than an hypothesis, and it will afterwards own that magnetic phenomena appear to result from electrical cur-circulating in magnetic bodies; a mode of view which connects the y of magnetism with that of electricity.

Precise definition of poles.—By the aid of the preceding hypo-we are enabled to obtain a clearer idea of the distribution of the etism in a magnetised bar, and to account for the circumstance that is no free magnetism in the middle of the bar, and that it is strongest poles. If AB (fig. 506) represent a magnet, then the alternate black hite spaces may be taken to represent the position of the magnetic in a series of particles after magnetisation; in accordance with what has been said, the white spaces, representing the south fluid, all poi one direction, and the north fluid in the opposite direction. The last

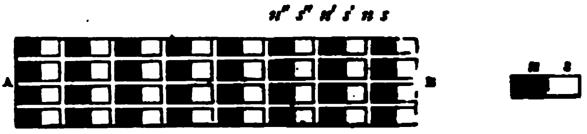


Fig. 506.

of the terminal molecule at one end would have north polarity, and other south polarity. Let N represent the north pole of a magnetic n placed near the magnet AB ; then the south fluid, s, in the terminal cule would tend to attract N, and the north fluid n would tend to rep but as the molecule of south fluid s is nearer N than the molecule of fluid n, the attraction between s and N would be greater than the rep between n and N. Similarly the attraction between s' and N wo greater than the repulsion between n' and N, and so on with the fol s'' and n'', etc. And all these forces would give a resultant tending attract N, whose point of application would have a certain fixed positi which would be the south pole of AB. In like manner it might be show that the resultant of the forces acting at the other end of the bar wou form a north pole, and would hence repel the north pole of the needle, b would attract its south pole.

That such a series of polarised particles really acts like an ordina magnet may be shown by partly filling a glass tube with steel filings, a passing the pole of a strong magnet five or six times along the outside one constant direction, taking care not to shake the tube. The individ filings will thus be magnetised, and the whole column of them prese to a magnetic needle will attract and repel its poles just like an ordin bar magnet, exhibiting a north pole at one end, a south pole at the oth and no polarity in the middle ; but on shaking the tube, or turning out filings, and putting them in again so as to destroy the regularity, eve trace of polarity will disappear.

It appears hence that the polarity at each end of a magnet is caused the fact that the resultant action on a magnetic body is strongest near ends, and does not arise from an accumulation of the magnetic fluids the ends.

The same point may be illustrated by the following experiment, wh is due to Grove. In a glass tube with flat glass ends is placed water which is diffused magnetic oxide of iron. Round the outside of the tu is coiled some insulated wire. On looking at a light through the tube liquid appears dark and muddy, but on passing a current of electric through the wire it becomes clearer. This is due to the particles sett with their longest dimension parallel to the axis of the tube, in wh position they obstruct the passage of light to a less extent.

634. **Experiment with broken magnets.**—That the magnetic flu are present in all parts of the bar, and not simply accumulated at the en

is also evident from the following experiment. A steel knitting-needle is magnetised by friction with one of the poles of a magnet, and then, the existence of the two poles and of the neutral line having been ascertained by means of iron filings, it is broken in the middle. But now, on presenting successively the two halves to a magnet, each will be found to possess two opposite poles and a neutral line, and in fact is a perfect magnet. If these new magnets are broken in turn in two halves, each will be a complete magnet with its two poles and neutral line, and so on, as far as the division can be continued. It is, therefore, concluded by analogy that the smallest parts of a magnet, the ultimate molecules, contain the two fluids.

635. **Magnetic induction.**—When a magnetic substance is placed in contact with a magnet, the two fluids of the former become separated; and so long as the contact remains, it is a complete magnet, having its two poles and its neutral line. For instance, if a small cylinder of soft iron *ab* (fig. 507), be placed in contact with one of the poles of a magnet, the cylinder can in turn support a second cylinder; this in turn a third and so on, to as many as seven or eight, according to the power of the magnet. Each of these little cylinders is a magnet; if it be the north pole of the magnet to which the cylinders are attached, the part *a* will have south, and *b* north magnetism; *b* will in like manner develope in the nearest end of the next cylinder south magnetism, and so on. But these cylinders are only magnets so long as the influence of a magnetised bar continues. For, if the first cylinder be removed from the magnet, the other cylinders mmediately drop, and retain no trace of magnetism. The separation of he two fluids is only momentary, which proves that the magnet yields othing to the iron. Hence we may have *temporary* magnets as well as *ermanent* magnets: the former of iron and nickel, the latter of steel nd cobalt. How this difference in action is explained will be shown irectly.

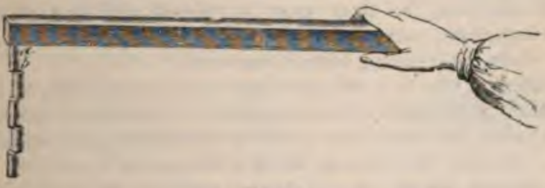


Fig. 507.

This action, in virtue of which a magnet can develope magnetism in ron, is called *magnetic induction* or *influence*, and it can take place without actual contact between the magnet and the iron, as is seen in the ollowing experiment. A bar of soft iron is held with one end near a magnetic needle. If now the north pole of a magnet be approached to the ron without touching it, the needle will be attracted or repelled, according as its south or north pole is near the bar. For the north pole of the magnet will develope south magnetism in the end of the bar nearest it, and therefore north magnetism at the other end, which would thus attract the south, but repel the north end of the needle. Obviously, if the other end of the magnet were brought near the iron, the opposite effects would be produced on the needle; or if the opposite pole of a second magnet of equal strength simultaneously be brought near the iron, the needle would be unaffected, as one magnet would outdo the work of the other.

Among other things, magnetic induction explains the formation of the tufts of iron filings which become attached to the poles of magnets. The parts in contact with the magnet are converted into magnets; these act inductively on the adjacent parts, these again on the following ones, and so on producing a filamentary arrangement of the filings.

636. **Coercive force.**—We have seen from the above experiments that soft iron becomes instantaneously magnetised under the influence of a magnet, but that this magnetism is not permanent, and ceases when the magnet is removed. Steel likewise becomes magnetised by contact with a magnet, but the operation is effected with difficulty, and the more so as the steel is more highly tempered. Placed in contact with a magnet, a steel bar acquires magnetic properties very slowly, and to make the magnetism complete, the steel must be rubbed with one of the poles. But this magnetism, once evoked in steel, is permanent, and does not disappear when the inducing force is removed.

These different effects in soft iron and steel are ascribed to a *coercive force*, which, in a magnetic substance, offers a resistance to the separation of the two fluids, but which also prevents their recombination when once separated. In steel this coercive force is very great, in soft iron it is very small or almost absent. By oxidation, pressure, or torsion, a certain amount of coercive force may be imparted to soft iron; and by heat, hammering, etc., the coercive force may be lessened, as will be afterwards seen.

637. **Difference between magnets and magnetic substances.**—*Magnetic substances* are substances which, like iron, steel, nickel, are attracted by the magnet. They contain the two fluids, but in a state of neutralisation. Compounds containing iron are usually magnetic, and the more so in proportion as they contain a larger quantity of iron. Some, however, like iron pyrites, are not attracted by the magnet.

A magnetic substance is readily distinguished from a magnet. The former has no poles; if successively presented to the two ends of a magnetic needle, *ab* (fig. 504), it will attract both ends equally, while a magnet would attract the one, but repel the other. Magnetic substances also have no action on each other, while magnets attract or repel each other, according as unlike or like poles are presented.

Iron is not the only substance which possesses magnetic properties; nickel has considerable magnetic power, but far less than that of iron; cobalt is less magnetic than nickel; while to even a slighter extent chromium and manganese are magnetic. Further, we shall see that powerful magnets exert a peculiar influence on all substances.

CHAPTER II.

TERRESTRIAL MAGNETISM. COMPASSES.

638. **Directive action of the earth on magnets.**—When a magnetised needle is suspended by a thread, as represented in fig. 504, or when placed on a pivot on which it can move freely (fig. 508), it ultimately sets in a position which is more or less north and south. If removed from this position, it always returns to it after a certain number of oscillations.

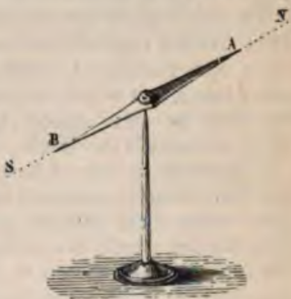


Fig. 508.

Analogous observations have been made in different parts of the globe, from which the earth has been compared to an immense magnet, whose poles are very near the terrestrial poles, and whose neutral line virtually coincides with the equator.

The polarity in the northern hemisphere is called the *northern* or *boreal* polarity, and that in the southern hemisphere the *southern* or *austral* polarity. In French works the end of the needle pointing north is called the *austral* or *southern* pole, and that pointing to the south, the *boreal* or *northern* pole ; a designation based on this hypothesis of a terrestrial magnet, and on the law that unlike magnetisms attract each other. In practice it will be found more convenient to use the English names, and call that end of the magnet which points to the north the *north pole*, and that which points to the south the *south pole*. That end of the needle pointing north is in England sometimes spoken of as the *marked end* of the needle.

639. **Terrestrial magnetic couple.**—From what has been stated, it is clear that the magnetic action of the earth on a magnetised needle may be compared to a *couple*, that is, to a system of two equal forces, parallel, but acting in contrary directions.

For let *ab* (fig. 509) be a moveable magnetic needle making an angle with the magnetic meridian MM′ (640). The earth's north pole acts attractively on the marked pole, *a*, and repulsively on the other pole, *b*, and two contrary forces are produced, *an*, and *bn′*, which are equal and parallel: for the terrestrial pole is so distant, and the needle so small, as to justify the assumption that the two directions *an* and *bn′* are parallel, and that the two poles are equidistant from the earth's north pole. But the earth's south pole acts similarly on the poles of the needle, and produces two other forces, *as* and *bs′*, which are also equal and parallel, but the two forces *an* and *as* may be reduced to a single resultant *a*N (33), and the forces *bn′* and *bs′* to a resultant *b*S ; these two forces *a*N and *b*S are equal, parallel, and act in opposite directions, and they constitute the *terrestrial magnetic couple* ; it is this couple which makes the needle set

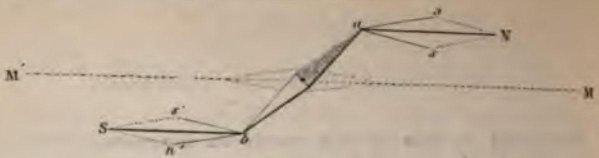


Fig. 509.

ultimately in the magnetic meridian, a position in which the two forces N and S are in equilibrium.

The force which determines the direction of the needle thus is neither attractive nor repulsive, but simply directive. If a small magnet be placed on a cork floating in water, it will at first oscillate, and then gradually move into a line which is virtually north and south. But if the surface of the water be quite smooth, the needle will not move either towards the north or towards the north.

If, however, a magnet be approached to a floating needle, attraction or repulsion ensues, according as one or the other of the poles is presented. The reason of the different actions exerted by the earth and by a magnet on a floating needle is as follows :—When the north pole, for instance, of the magnet is presented to the south pole of the needle, the latter is attracted ; it is, however, repelled by the south pole of the magnet. Now the force of magnetic attraction or repulsion decreases with the distance, and as the distance between the south pole of the needle and the north pole of the magnet is less than the distance between the south pole of the needle and the south pole of the magnet, the attraction predominates over the repulsion, and the needle moves towards the magnet. But the earth's magnetic north pole is so distant from the floating needle that its length may be considered infinitely small in comparison, and one pole of the needle is just as strongly repelled as the other is attracted.

640. **Magnetic elements. Declination.**—In order to obtain a full knowledge of the earth's magnetism at any place three essentials are requisite, these are: i. Declination ; ii. Inclination ; iii. Intensity. These three are termed the *magnetic elements* of the place. We shall explain them in the order in which they stand.

The *geographical meridian* of a place is the imaginary plane passing through this place and through the two terrestrial poles, and the *meridian* is the outline of this plane upon the surface of the globe. Similarly the *magnetic meridian* of a place is the vertical plane passing at this place through the two poles of a moveable magnetic needle in equilibrium about a vertical axis.

In general the magnetic meridian does not coincide with the geographical meridian, and the angle which the magnetic makes with the geographical meridian, or, what is the same thing, the angle which the direction of the needle makes with the meridian, is called the *declination* or *varia-*

on of the magnetic needle. The declination is said to be *east* or *west*, ccording as the north pole of the needle is to the east or west of the eographical meridian.

641. **Variations in declination.**—The declination of the magnetic eedle, which varies in different places, is at present west in Europe and n Africa, but east in Asia and in the greater part of North and South merica. It shows further considerable variations even in the same lace; these variations are of two kinds; some are regular, and are ither secular, annual, or diurnal; others, which are irregular, are called *rturbations* or *magnetic storms.*

Secular variations.—In the same place, the declination varies in the ourse of time, and the needle appears to make oscillations to the east nd west of the meridian, the duration of which is several centuries. The eclination has been known at Paris since 1580, and the following table epresents the variations which it has undergone:—

Year	Declination	Year	Declination
1580	11° 30′ E.	1825	22° 22′ W.
1663	0	1830	22° 12′ W.
1700	8° 10′ W.	1835	22° 4′ W.
1780	19° 55′ W.	1850	20° 30′ W.
1785	22° W.	1855	19° 57′ W.
1805	22° 5′ W.	1860	19° 32′ W.
1814	22° 34′ W.	1865	18° 44′ W.

This table shows that since 1580 the declination has varied at Paris as uch as 34°, and that the greatest westerly declination was attained in 14, since which time the needle has gradually tended towards the east.

At London, the needle showed in 1580 an east declination of 11° 36′; 1663 it was at zero; from that time it gradually tended towards the est, and reached its maximum declination of 24° 41′ in 1818; since then has steadily diminished; it was 22° 30′ in 1850, and is now (1873) ° 32′ W.

At Yarmouth and Dover the variation is about 40′ less than at London; Hull and Southampton about 20′ greater; at Newcastle and Swansea out 1° 15′, and at Liverpool 1° 30′, at Edinburgh 2° 5′, and at Glasgow d Dublin about 2° 25′, greater than at London.

The following are the observations of the magnetic elements at Kew r the last six years.

Year	Declination	Inclination	Horizontal Intensity
1865	20° 59′	68° 7′	3·829
1866	20° 51′	68° 6′	3·837
1867	20° 40′	68° 3′	3·844
1868	20° 33′	68° 2′	3·848
1869	20° 25′	68° 1′	3·852
1870	20° 19′	67° 58′	3·857

In certain parts of the earth the magnet coincides with the geographical meridian. These points are connected by an irregularly curved imaginary line, called *a line of no variation*, or *agonic line*. Such a line cuts the east of South America, and, passing east of the West Indies, enters North America near Philadelphia, and traverses Hudson's Bay; thence it passes through the North Pole, entering the Old World east of the White Sea, traverses the Caspian, cuts the east of Arabia, turns then towards Australia, and passes through the South Pole, to join itself again.

Isogonic lines are lines connecting those places on the earth's surface in which the declination is the same. The first of the kind was constructed in 1700 by Halley; as the elements of the earth's magnetism are continually changing, the course of such a line can only be determined for a certain time. One of the newest set of isogonic lines has been constructed by Captain Evans for the year 1857, and is given in the British Association Report for 1861.

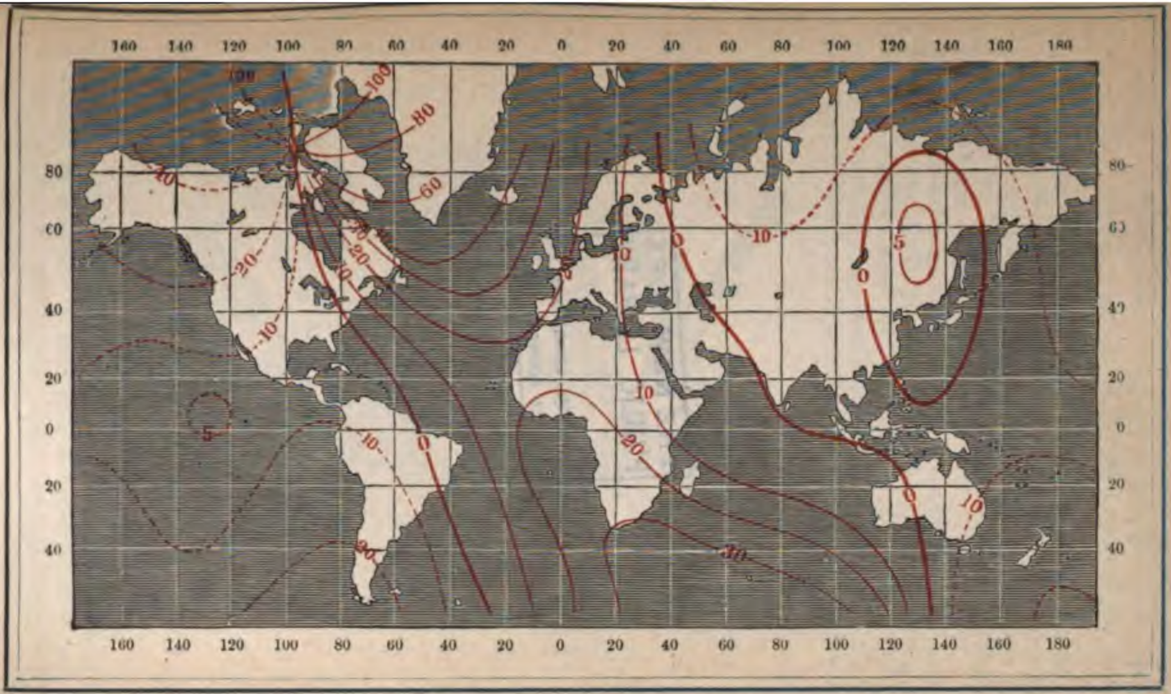
Maps on which such isogonic lines are depicted are called *declination maps*; and a comparison of these in various years is well fitted to show the variations which this magnetic element undergoes. Plate III. represents a map in Mercator's projection giving these lines for the year 1860. It extends from 80° N. to 60° S. latitude, and from the nature of the case cannot include both poles, for which a map in polar projection is needed. The figures attached to the red lines represent the observed angles of declination; the dotted red lines are the result of calculation.

642. **Annual variations.**—Cassini first discovered in 1780 that the declination is subject to small annual variations. At Paris and London it is greatest about the vernal equinox, diminishes from that time to the summer solstice, and increases again during the nine following months. It does not exceed from 15′ to 18′, and it varies somewhat at different epochs.

The *diurnal variations* were first discovered by Graham in 1722; they can only be observed by means of long needles or delicate indicators such as the reflection of a ray of light and very sensitive instruments. In this country the north pole moves every day from east to west from sunrise until one or two o'clock; it then tends towards the east, and at about ten o'clock regains its original position. During the night the needle is almost stationary. Thus the westerly declination is greatest during the warmest part of the day.

At Paris the mean amplitude of the diurnal variation from April to September is from 13′ to 15′, and for the other months from 8′ to 10′. On some days it amounts to 25′, and on others does not exceed 5′. The greatest variation is not always at the same time. The amplitude of the daily variations decreases from the poles towards the equator, where it is very feeble. Thus in the island of Rewak it never exceeds 3′ to 4′.

643. **Accidental variations and perturbations.**—The declination is accidentally disturbed in its daily variations by many causes, such as earthquakes, the *aurora borealis*, and volcanic eruptions. The effect of the aurora is felt at great distances. Auroras which are only visible in the north of Europe act on the needle even in these latitudes, where



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ental variations of 20′ have been observed. In polar regions the e frequently oscillates several degrees; its irregularity on the day e the aurora borealis is a presage of the occurrence of this pheno- n.

other remarkable phenomenon is the simultaneous occurrence of etic perturbations in very distant countries. Thus Sabine mentions gnetic disturbance which was felt simultaneously at Toronto, the , Prague, and Van Diemen's Land. Such simultaneous perturbations received the name of *magnetic storms.*

. **Declination compass.**—The *declination compass* is an instrument hich the magnetic declination of any place may be measured when tronomical meridian is known. It consists of a brass box, AB (fig. in the bottom of which is a graduated circle, M. In the centre is a , on which oscillates a very light lozenge-shaped magnetic needle, *ab*.

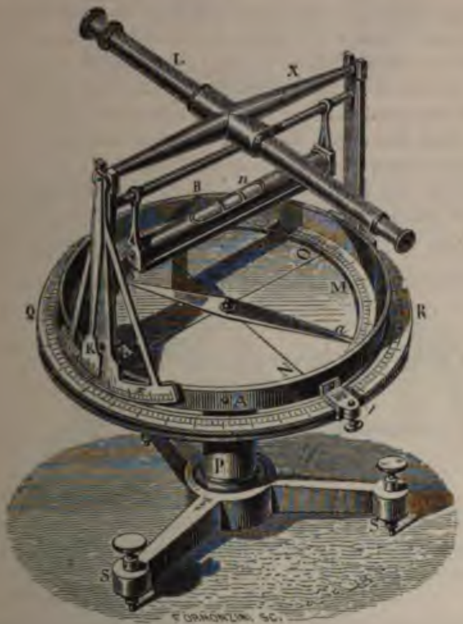

Fig. 510.

e box are attached two uprights supporting a horizontal axis, X, hich is fixed an astronomical telescope, L, moveable in a vertical . The box rests on a foot, P, about which it can turn in a horizontal , taking with it the telescope. A fixed circle, QR, which is called *zimuthal circle*, serves to measure the number of degrees through h the telescope has been turned, by means of a vernier, V, fixed to the box. The inclination of the telescope, in reference to the horizon, may be measured by another vernier, K, which moves with the axis of the telescope, and is read off on a fixed graduated arc, *x*.

The first thing in determining the declination is to range the compass horizontally by means of the screws, SS, and the level, *n*. The astronomical meridian is then found either by an observation of the sun at noon exactly, or by any of the ready methods known to astronomers. The box, AB, is then turned until the telescope is in the plane of the astronomical meridian. The angle made by the magnetic needle with the diameter, N, which corresponds with the zero of the scale, and is exactly in the plane of the telescope, is then read off on the graduated limb, and this is east or west, according as the pole, *a*, of the needle stops at the east or west of the diameter, N.

645. **Correction of errors.**—These indications of the compass are only correct when the magnetic axis of the needle, that is, the right line passing through the two poles, coincides with its axis of figure, or the line connecting its two ends. This is not usually the case, and a correction must therefore be made, which is done by the *method of reversion*. For this purpose the needle is not fixed in the cap, but merely rests on it, so that it can be removed and its position reversed; thus what was before the lower is now the upper face. The mean between the observations made in the two cases gives the true declination.

For, let NS be the astronomical meridian, *ab* the axis of figure of the needle, and *mn* its magnetic axis. The true declination is not the arc N*a* but the arc N*m*, which is greater. If now the needle be turned, the line

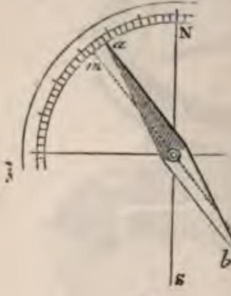

Fig. 511.

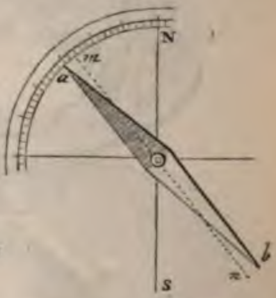

Fig. 512.

mn makes the same angle with the meridian NS; but the north end of the needle which was on the right of *mn* is now on the left (fig. 512), so that the declination which was previously too small by a certain amount, is now too large by the same amount. Hence the true declination is given by the mean of these two observations.

646. **Mariner's compass.**—The magnetic action of the earth has received a most important application in the *mariner's compass*. This is a declination compass used in guiding the course of a ship. Figure 513 represents a view of the whole, and figure 514 a vertical section. It con-

sts of a cylindrical case, which to keep the compass in a horizontal sition in spite of the rolling of the vessel, is supported on *gimbals.* hese are two concentric rings, one of which attached to the case itself

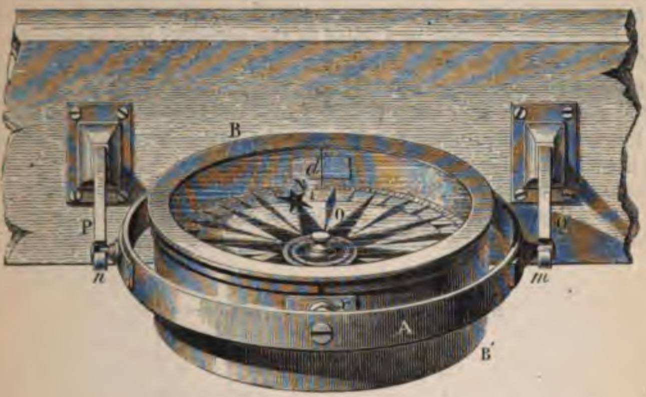

Fig. 513

oves about the axis *cd* which plays in the outer ring AB, and this moves the supports PQ, about the axis *mn* at right angles to the first.

In the bottom of the box is a pivot, on which is placed, by means of an ate cap, a magnetic bar *ab*, which is the needle of the compass. On is is fixed a disc of mica, a little larger than the length of the needle,

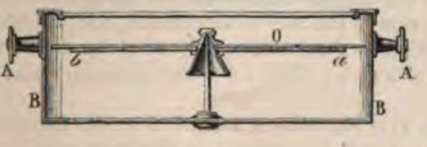

Fig. 514.

which is traced a star or *rose* with thirty-two branches, making the ht points or *rhumbs* of the wind, the demi-rhumbs and the quarters. e branch ending in a small star and called N, corresponds to the bar which is underneath the disc.

The compass is placed near the stern of the vessel in the *binnacle.* owing the direction of the compass in which the ship is to be steered, pilot has the rudder turned till the direction coincides with the sight e passing through a line *d* marked on the inside of the box, and allel with the keel of the vessel.

Neither the inventor of the compass, nor the exact time of its invention, nown. Guyot de Provins, a French poet of the twelfth century, first tions the use of the magnet in navigation, though it is probable that Chinese long before this had used it. The ancient navigators, who

the vertical plane, in which it moves, coincides with t
meridian, is called the *inclination* or *dip* of the needle. I

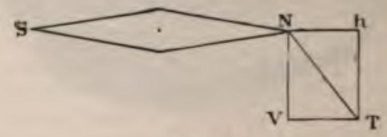

Fig. 515.

plane than the magnetic meridian, the inclination *increases*,
a plane at right angles to the magnetic meridian. For t
inclination is the resultant of two forces, one acting in a h
the other in a vertical plane. When the needle is moved sc
right angles to the magnetic meridian, the horizontal compon
act in the direction of the axis of suspension, and, therefore,
the needle, which is then solely influenced by the vertical
and stands vertically. The following considerations wil
clearer :—

Let NS (fig. 515) represent a magnetic needle capable of
vertical plane. Let NT represent in direction and intensi
force of the earth's magnetism acting on the pole N. Ther
resolved into the forces N*h* and N*v* ; TN*h* being the angle
or dip.

NT is termed the *total force*, and its components
N*h*, or the *horizontal force*, and
N*v*, or the *vertical force*.

Now, it is clear that the greater the angle of dip, TN*h*, the
N*h*, or the horizontal force, and the greater N*v*, or the v
Hence, in high latitudes, the directive force of a compass w

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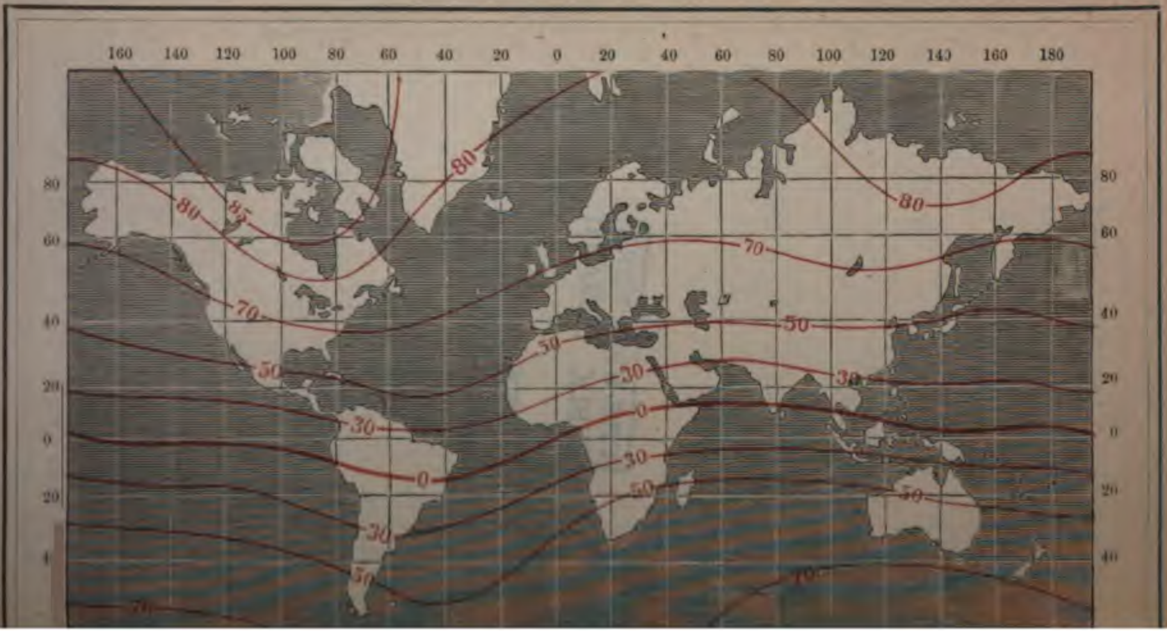
Plate IV.

ISOCLINIC LINES FOR THE YEAR 1860.



the strength of the earth's magnetism is measured, become fewer and fewer as the magnetic poles are approached, although there is really an increase in the total force of the earth.

Again, the reason why a dipping-needle stands vertical when placed E. and W. is clearly because in those positions the horizontal force now acting at right angles to the plane of motion of the needle is ineffectual to move it, and therefore merely produces a pressure on the pivot which supports the needle. But the vertical component of the total force remains unaffected by the new position of the needle. Acting, therefore, entirely alone when the dipping-needle is exactly E. and W., this vertical component drags the needle into a line with itself, that is, 90° from the horizontal plane.

The value of the dip, like that of the declination, differs in different localities. It is greatest in the polar regions, and decreases with the latitude to the equator, where it is approximately zero. In London at the present time, 1813, the dip is 67° 49′, reckoning from the horizontal line. In the southern hemisphere the inclination is again seen, but in a contrary direction, that is, the south pole of the needle dips below the horizontal line.

The *magnetic poles* are those places in which the dipping-needle stands vertical, that is, where the inclination is 90°. In 1830 the first of these, the terrestrial north pole, was found by Sir James Ross in 96° 43′ west longitude and 70° north latitude. The same observer found in the South Sea, in 76° south latitude and 168° east longitude, that the inclination was 88° 37′. From this and other observations, it has been calculated that the position of the magnetic south pole was at that time in about 154° east longitude and 75½° south latitude.

The line of no declination passes through these poles, and the lines of equal declination converge towards them.

The *magnetic equator* or *aclinic line* is the line which joins all those places on the earth where there is no dip that is, all those in which the dipping-needle is quite horizontal. It is a somewhat sinuous line, not differing much from a great circle inclined to the horizon at an angle of 12°, and cutting it on two points almost exactly opposite each other, one in the Atlantic, and one in the Pacific. These points appear to be gradually moving their position, and travelling from east to west.

Lines connecting places in which the dipping-needle makes equal angles are called *isoclinic lines.*

Plate IV. is an inclination map for the year 1860, the construction of which is quite analogous to that of the map of declination.

The inclination is subject to secular variations, like the declination, as is readily seen from a comparison of maps of inclination for different epochs. At Paris, in 1671, the inclination was 75°; since then it has been continually decreasing, and in 1859 was 66° 14′. In London also the dip has continually diminished since 1720 by about 2·6′ per annum. In 1821 it was 70° 3′; in 1838, 69° 17′; in 1854 it was 68° 31′; in 1859 it was 68° 21′; it is now (1873) 67° 49′. It is also subject to slight annual and diurnal variations, as we have said; being, according to Hanstein, about 15′

greater in summer than in winter, and 4′ or 5′ greater before noon after.

648. **Inclination compass.**—An inclination compass is an instru for measuring the magnetic inclination or dip. It consists of a grad horizontal brass circle, *m* (fig. 516), supported on three legs, pro

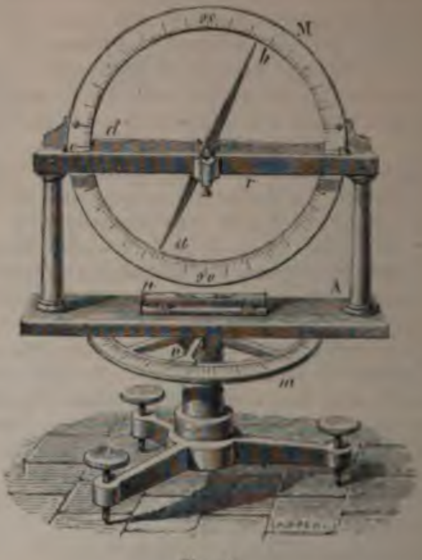


Fig. 516.

with levelling screws. Above this circle there is a plate, A, move about a vertical axis, and supporting by means of two columns a se graduated circle, M, which measures the inclination. The needle on a frame, *r*, and the diameter passing through the two zeros of circle, M, can be ascertained to be perfectly horizontal by means of spirit level, *n*.

To observe the inclination, the magnetic meridian must first be d mined, which is effected by turning the plate A on the circle *m*, unti needle is vertical, which is the case when it is in a plane at right an to the magnetic meridian (647). The plate A is then turned 90° on circle *m*, by which the vertical circle, M, is brought into the mag meridian. The angle, *dca*, which the magnetic needle makes with horizontal diameter, is the angle of inclination.

There are here several sources of error, which must be allowed The most important are three :—i. The magnetic axis of the needle not coincide with its axis of figure : hence an error, which is correcte a method of reversion analogous to that already described (645). ii. centre of gravity of the needle may not coincide with the axis of sus sion, and then the angle, *dca*, is too great or too small, according as centre of gravity is below or above the centre of suspension ; for in the first case the action of gravity is in the same direction as that of magnetism, and in the second is in the opposite direction. To correct this error, the poles of the needle must be reversed by first demagnetising it, and then imparting a contrary magnetism to what it had at first. The inclination is now redetermined, and the mean taken of the results obtained in the two groups of operations. iii. The plane of the ring may not coincide with the true magnetic meridian. It should be in that plane when the needle has its minimum deviation ; an observation of this kind should therefore be taken along with that previously described, by which the needle is moved 90° from its maximum deviation.

649. **Astatic needle and astatic system.**—An *astatic needle* is one which is uninfluenced by the earth's magnetism. A needle moveable about an axis in the plane of the magnetic meridian and parallel to the inclination would be one of this kind; for the terrestrial magnetic couple acting then in the direction of the axis cannot impart to the needle any determinate direction.

An *astatic system* is a combination of two needles of the same force joined parallel to each other with the poles in contrary directions, as shown in fig. 517. If the two needles have exactly the same magnetic force, the opposite action of the earth's magnetism on the poles a' and b and on the poles a and b' counterbalance each other ; the system is then completely astatic, and sets at right angles to the magnetic meridian.

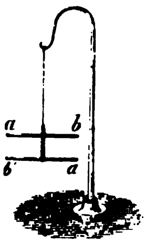


Fig. 517.

A single magnetic needle may also be rendered astatic by placing a magnet near it. By repeated trials a certain position and distance can be found at which the action of the magnet on the needle just neutralises that of the earth's magnetism, and the needle is free to obey any third force.

650. **Intensity of the earth's magnetism.**—If a magnetic needle be moved from its position of equilibrium, it will revert to it after a series of oscillations, which follow laws analogous to those of the pendulum (75). If the magnet be removed to another place, and caused to oscillate during the same length of time as the first, a different number of oscillations will be observed. And the intensity of the earth's magnetism in the two places will be respectively proportional to the squares of the number of oscillations.

If at M the number of oscillations in a minute had been $25 = n$, and at another place, M′, $24 = n'$, we should have—

$$\frac{\text{Intensity of the earth's magnetism at M}}{\text{Intensity of the earth's magnetism at M}'} = \frac{n^2}{n'^2} = \frac{625}{576} = 1\cdot085.$$

That is, if the intensity of the magnetism at the second place is taken as unity, that of the first is 1·085. If the magnetic condition of the needle had not changed in the interval between the two observations, this method would give the relation between the intensities at the two places.

In these determinations of the intensity, it would be necessary to h the oscillations of the dipping-needle, which are produced by the wh force of the earth's magnetism. These, however, are difficult to obt with accuracy, and, therefore, the oscillations of the decli tion needle are usually taken. The force which makes t declination needle oscillate is only a portion of the to magnetic force, and is smaller in proportion as the incli tion is greater. If the line *ac* (fig. 518) = M represents t total intensity, the angle *i* the inclination, then the horizon component *ab* [illegible] Hence, to express the intensiti in the two pla [illegible] scillations of the declination need we must subs [illegible] preceding equation the values cos *i* and M′ [illegible] and M′, and we have—

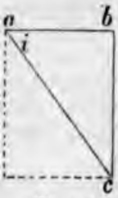


Fig. 518.

$$\frac{M \cos i}{M' \cos i'}, \text{[illegible]} \frac{M}{M'} = \frac{n^2 \cos i'}{n'^2 \cos i}.$$

That is to say, having ob [illegible] vo different places the number oscillations, *n* and *n′*, that [illegible] eedle makes in the same time, t ratio of the magnetic force [illegible] places will be found by multiply the ratio of the square of the number of oscillations by the inverse ra of the cosine of the angle of inclination.

The magnetic intensity increases with the latitude. Humboldt found point of minimum intensity on the magnetic equator in Northern Pe This value is frequently taken as the unit to which magnetic intensities other places are referred, as in the following table :—

Locality	Date	Latitude	Magnetic Intensity
St. Anthony	1802	0·0°	1·087
Carthagena	1801	10·25 N.	1·294
Naples	1805	40·50	1·274
Paris	1800	48·52	1·348
Berlin	1829	52·51	1·366
Petersburg	1828	59·66	1·410
Spitzbergen	1823	79·40	1·567

According to Gauss the total magnetic action of the earth is the sam as that which would be exerted if in each cubic yard there were eight ba magnets each weighing a pound.

The lines connecting places of equal intensity are called *isodynami lines.* They are not parallel to the magnetic equator, but appear to hav about the same direction as the isothermal lines.

According to Kuppfer, the intensity appears to diminish at greate heights ; a needle which made one oscillation in 24″ vibrated more slowl by 0·01″ at a height of 1,000 feet ; but, according to Forbes, the intensit is only $\frac{1}{1000}$ less at a height of 3,000 feet.

The intensity varies in the same place with the time of day ; it attai its maximum between 4 and 5 in the afternoon, and is at its minimu between 10 and 11 in the morning.

It is probable, though it has not yet been ascertained with certainty the intensity undergoes secular variations. From measurements of total force made monthly at Kew between 1857 and 1862, it appeared the total force experienced a very slight annual increase.

uring the last few years great attention has been devoted to the ob- ation of the magnetic elements, and observatories for this purpose e been fitted up in different parts of the globe. These observations e led to the discovery that the magnetism of the earth is in a state of stant fluctuation, like the waves of the sea. And in studying the ations of the declination, etc., the mean of a great number of obser- ons must be taken, so as to eliminate the irregular disturbances, and g out the general laws.

he observations made in the English magnetic observatories have been ıced by Sabine, and have revealed some curious facts in reference to magnetic storms. He finds that there is a certain periodicity in their earance, and that they attain their greatest frequency about every ten s. Independently of this, Schwabe, a German astronomer, who had ied the subject many years, has found that the spots on the sun, seen ooking at it through a coloured glass, vary in their number, size, and uency, but attain their maximum between every ten or eleven years. v Sabine has established the interesting fact that the period of their itest frequency coincides with the period of greatest magnetic disturb- e. Other remarkable connections between the sun and terrestrial netism have been observed; one, especially, of recent occurrence, has acted considerable attention. It was the flight of a large luminous s across a vast sun spot, while a simultaneous perturbation of the netic needle was observed in the observatory at Kew; subsequent nination of magnetic observations in various parts of the world ved that within a few hours one of the most violent magnetic storms known had prevailed.

agnetic storms are nearly always accompanied by the exhibition of aurora borealis in high latitudes; that this is not universal may be to the fact that many auroras escape notice. The converse of this is , that no great display of the aurora takes place without a violent netic storm.

CHAPTER III.

LAWS OF MAGNETIC ATTRACTIONS AND REPULSIONS.

1. **Law of decrease with distance.**—Coulomb discovered the re- kable law in reference to magnetism, *that magnetic attractions and lsions are inversely as the square of the distances.* He proved this by ns of two methods :—(i.) that of the torsion balance, and (ii.) that of llation.

2. i. **The torsion balance.**—This apparatus depends on the prin- e that, when a wire is twisted through a certain space, the angle of ion is proportional to the force of torsion (84). It consists (fig. 519) glass case closed by a glass top, with an aperture near the edge, to

allow the introduction of a magnet, A. In another aperture in t
of the top a glass tube fits, provided at its upper extremit
micrometer. This consists of two circular pieces: *d*, which
is divided on the edge into 360°, while one *e*, which is movea
is a mark, *c*, to indicate its rotation. D and E represent the t
of the micrometer on a larger scale. On E there are two
connected by a horizo
on which is a very f
wire supporting a
needle, *ab*. On the si
case there is a graduat
which indicates the an
needle *ab*, and hence th
of the wire.

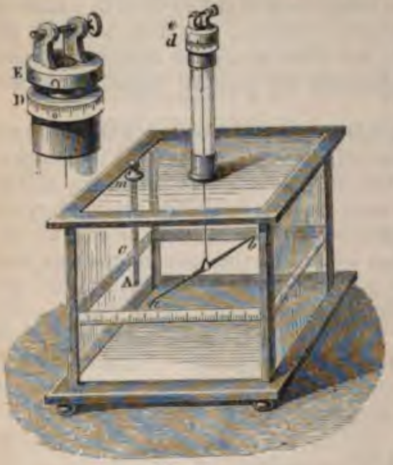


Fig. 519.

When the mark *c* of
E is at zero of the scal
case is so arranged that
supporting the needle
zero of the scale in the
in the magnetic meridi
needle is then removed
stirrup, and replaced b
actly similar one of c
any unmagnetic substa
tube, and with it the
and E, are then turne
the needle stops at zero of the graduation. The magnetic ne
being now replaced, is exactly in the magnetic meridian, and
exerts no torsion.

Before introducing the magnet, A, it is necessary to investi
action of the earth's magnetism on the needle *ab*, when the latt
moved out of the magnetic meridian. This will vary with the dir
and force of the needle, with the dimensions and nature of the p
wire used, and with the intensity of the earth's magnetism in the
observation. Accordingly, the piece E is turned until *ab* makes
angle with the magnetic meridian. Coulomb found in his exp
that E had to be turned 35° in order to move the needle through
is, the earth's magnetism was equal to a torsion of the wire corres
to 35°. As the force of torsion is proportional to the angle of torsi
the needle is deflected from the meridian by 2, 3 . . . degr
directive action of the earth's magnetism is equal 2, 3 . . . times

The action of the earth's magnetism having been determi
magnet A is placed in the case so that similar poles are oppo
other. In one experiment Coulomb found that the pole *a* was
through 24°. Now the force which tended to bring the needle
magnetic meridian was represented by $24° + 24 \times 35 = 864$, of w
part 24° was due to the torsion of the wire, and $24 \times 35°$ was the
lent in torsion of the directive force of the earth's magnetism.
needle was in equilibrium, it is clear that the repulsive force whi

balanced those forces must be equal to 864°. The disc was then ied until *ab* made an angle of 12°. To effect this, eight complete itions of the disc were necessary. The total force which now tended ring the needle into the magnetic meridian was composed of :—1st, 12° of torsion by which the needle was distant from its starting point; , of 8 × 360° = 2880, the torsion of the wire ; and, 3rd, the force of the h's magnetism, represented by a torsion of 12 × 35°. Hence, the es of torsion which balance the repulsive forces exerted at a distance 4° and of 12° are—

24°	864
12°	3312

low, 3312 is very nearly four times 864 ; hence, for half the distance repulsive force is four times as great.

53. ii. **Method of oscillations.**—A magnetic needle oscillating er the influence of the earth's magnetism may be considered as a dulum, and the laws of pendulum motion apply to it. The method of illations consists in causing a magnetic needle to oscillate first under influence of the earth's magnetism alone, and then successively under combined influence of the earth's magnetism, and of a magnet placed inequal distances.

'he following determination by Coulomb will illustrate the use of the hod. A magnetic needle was used which made 15 oscillations in a ute under the influence of the earth's magnetism alone. A magnetic about 2 feet long was then placed vertically in the plane of the magc meridian, so that its north pole was downwards and its south pole sented to the north pole of the oscillating needle. He found that at stance of 4 inches the needle made 41 oscillations in a minute, and at istance of 8 inches 24 oscillations. Now, from the laws of the penım (51), the intensity of the forces are inversely as the squares of the es of oscillations. Hence, if we call M the force of the earth's magsm, *m* the attractive force of the magnet at the distance of 4 inches, at the distance of 8 inches, we have

$$\mathrm{M} : \mathrm{M} + m = 15^2 : 41^2, \text{ and}$$
$$\mathrm{M} : \mathrm{M} + m' = 15^2 : 24^2,$$

iinating M

$$m : m' = 41^2 - 15^2 : 24^2 - 15^2 = 1456 : 351$$
$$= 4 : 1 \text{ nearly},$$
$$m : m' = 4 : 1.$$

n other words, the force acting at 4 inches is quadruple that which at double the distance.

'he above results do not quite agree with the numbers required by the of inverse squares. But this could only be expected to apply in the e in which the repulsive or attractive force is exerted between two nts, and not, as is here the case, between the resultant of a system of nts. And it is to this fact that the discrepancy between the theoretical d observed results is due.

In the case of the torsion balance, one pole of the magnet to be tested is at so great a distance that it could not appreciably modify the action of the other. When the distance at which two magnets act is lar compared with their dimensions, the *total action* on one another is n inversely as the *third power* of the distances ; which, it might be sh is a necessary consequence of the law that the action of the mag elements is inversely as the square of the distance.

When a magnet acts upon a mass of soft iron, the law of the vari with the distance is modified. The attraction in this case is inve proportional to the distance between the magnet and the iron.

When the distance between the magnet and iron is small, Tyndall found that the attraction is directly proportional to the square of strength of the magnet : but when the iron and the magnet are in tact, then the attraction is directly proportional to the strength of magnet.

654. **Magnetic curves.**—If a stout sheet of paper stretched on a fr be held over a horse-shoe magnet, and then some very fine iron fil be strewn on the paper, on tapping the frame the filings will be foun arrange themselves in thread-like curved lines, stretching from pol pole (fig. 520). These lines form what are called *magnetic curves*; t

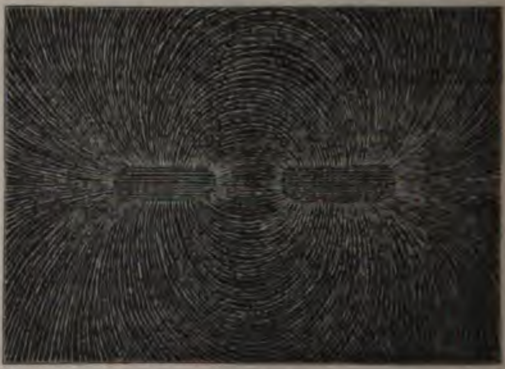


Fig. 520.

direction. The direction of the curve at any point represents the direct of magnetism at this point ; the *lines of magnetic force.*

To render these curves permanent, the paper on which they are form should be waxed ; if then a hot iron plate be held over them, this m the wax, which rises by capillary attraction (126) between the particle filings, and on subsequent cooling connects them together.

These curves are a graphic representation of the law of magn attraction and repulsion with regard to distance ; for under the influe of the two poles of the magnet, each particle itself becomes a mi magnet, the poles of which arrange themselves in a position depen on the resultant of the forces exerted upon them by the two poles, this resultant varies with the distance of the two poles respectively small magnetic needle placed in any position near the magnet will ta direction which is the tangent to the curve at this place.

CHAPTER IV.

PROCESSES OF MAGNETISATION.

55. **Magnetisation.**—The various sources of magnetism are the in-
nce of natural or artificial magnets, terrestrial magnetism, and elec-
ity. The three principal methods of magnetisation by magnets are
wn by the technical names of single touch, separate touch, and double
ch.

56. **Method of single touch.**—This consists in moving the pole of
owerful magnet from one end to the other of the bar to be magnetised,
l repeating this operation several times always in the same direction.
e neutral fluid is thus gradually decomposed throughout all the length
he bar, and that end of the bar which was touched last by the magnet
of opposite polarity to the end of the magnet by which it has been
ched. This method only produces a feeble magnetic power, and is,
ordingly, only used for small magnets. It has further the disadvan-
e of frequently developing consequent points.

57. **Method of separate touch.**—This method, which was first used
Dr. Knight in 1745, consists in placing the two opposite poles of two
gnets of equal force in the middle of the bar to be magnetised, and in
ving each of them simultaneously towards the opposite ends of the
. Each magnet is then placed in its original position, and this opera-
n repeated. After several frictions on both faces the bar is mag-
ised.

n Knight's method the magnets are held vertically. Duhamel per-
ted the method by inclining the magnets, as represented in fig. 521;
l still more, by placing the bar to be magnetised on the opposite poles
wo fixed magnets, the action of which strengthens that of the move-
e magnets. The relative position of the poles of the magnets is
icated in the figure.

his method produces the most regular magnets.

58. **Method of double touch.**—In this method, which was invented
Mitchell, the two magnets are placed with their poles opposite each
er in the middle of the bar to be magnetised. But, instead of moving
m in opposite directions towards the two ends, as in the method of
arate touch, they are kept at a fixed distance by means of a piece of
od placed between them (fig. 521), and are simultaneously moved first
ards one end, then from this to the other end, repeating this operation
eral times, and finishing in the middle, taking care that each half of
bar receives the same number of frictions.

pinus, in 1758, improved this method by supporting the bar to be
gnetised, as in the method of separate touch, on the opposite poles of
powerful magnets, and by inclining the bars at an angle of 15°
20°.

In practice, instead of two bar magnets it is usual to employ a horse-
oe magnet, which has its poles conveniently close together.

By this method of double touch, which is the one generally adopted powerful magnets are obtained, but they have frequently consequen

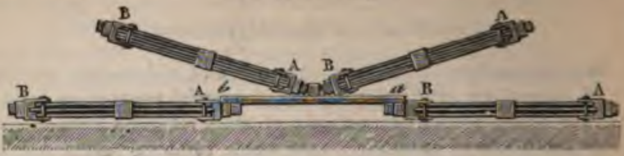


Fig. 521.

points. As this would be a serious injury to compass needles, these a best magnetised by separate touch.

659. **Magnetisation by the action of the earth.**—The action of th earth on magnetic substances resembles that of a magnet, and hence th terrestrial magnetism is constantly tending to separate the two fluids whic are in the neutral state in soft iron and in steel. But as the coerciv force is very considerable in the latter substance, the action of the ear is inadequate to produce magnetisation, except when continued for a lon time. This is not the case with perfectly soft iron. When a bar of th metal is held in the magnetic meridian parallel to the inclination, th neutral fluid is immediately decomposed, and the bar becomes endowe with feeble magnetic polarity. The lower extremity is a north pole, and the north pole of a small magnetic needle be approached, it will be r pelled. This magnetism is of course unstable, for if the bar be turne the poles are inverted, as pure soft iron is destitute of coercive force.

While the bar is in this position, a certain amount of coercive forc may be imparted to it by giving it several smart blows with a hamme and the bar retains for a short time the magnetism which it has thus ob tained. But the coercive force thus developed is very small, and after time the magnetism disappears.

If a bar of soft iron be twisted while held vertically, or, better, in th plane of the dip, it acquires a feeble permanent magnetism.

It is this magnetising action of the earth which developes the magne tism frequently observed in steel and iron instruments, such as fire-irons rifles, lamp posts, railing, lightning conductors, etc., which remain fo some time in a more or less inclined position. They become magnetised with their north pole downward, just as if placed over the pole of a powe ful magnet. The magnetism of native black oxide of iron has doubtless been produced by the same causes ; the very different magnetic power of different specimens being partly attributable to the different positions of the veins of ore with regard to the line of dip. The ordinary irons of commerce are not quite pure, and possess a feeble coercive force; hence a feeble magnetic polarity is generally found to be possessed by the tools in a smith's shop. Cast-iron, too, has usually a great coercive force, and can be permanently magnetised. The turnings, also, of wrought iron and of steel produced by the powerful lathes of our ironworks are found to be magnetised.

660. **Magnetism of iron ships.**—The inductive action of terrestrial agnetism upon the masses of iron always found in ships exerts a disrbing action upon the compass needle. This *local attraction*, as it is lled, may be so considerable as to render the indications of the needle most useless if it be not guarded against. A full account of the anner in which local attraction is produced, and in which it is comnsated, is inconsistent with the limits of this book, but the most portant points are the following:—

i. A vertical mass of soft iron in the vessel, say in the bows, would come magnetised under the influence of the earth; in the northern misphere, the lower end would be a north pole, and the upper end a uth pole; and as the latter may be assumed to be nearer the north le of the compass needle, it would act upon it. So long as the vessel is sailing in the magnetic meridian this would have no effect; but in y other direction the needle would be drawn out of the magnetic ridian, and a little consideration will show that when the ship was at ht angles to the magnetic meridian the effect would be greatest. is *vertical induction* would disappear twice in swinging the ship round, d would be at its maximum twice; hence the deviation due to this use is known as *semicircular deviation*.

i. Horizontal masses again, such as deck-beams, are also acted upon luctively by the earth's magnetism, and their induced magnetism rts a disturbing influence upon the magnetic needle. The effect of s horizontal induction will disappear when the ship is in the magnetic ridian, and also when it is at right angles thereto. In positions interdiate to the above the disturbing influence will attain its maximum. nce in swinging a ship round there would be four positions of the p's head in which the influence would be at a maximum and four in ich it would be at a minimum. This effect of horizontal induction is cordingly spoken of as *quadrantal deviation*.

The influence of both these causes, vertical and horizontal induction, y be remedied in the process of 'swinging the ship.' This consists in nparing the indications of the ship's compass with those of a standard npass placed on shore. The ship is then swung round in various itions, and by arranging small vertical and horizontal masses of soft n in proximity to the steering compass, positions are found for them in ich the inductive action of the earth upon them quite neutralises the luence of the earth's magnetism upon the ship; and in all positions of ship, the compass points in the same direction as the one on shore.

ii. The extended use of iron in ship-building, more especially when frames are entirely of iron, has increased the difficulty. In the cess of building a ship, the hammering and other mechanical opeions to which it is subject, while under the influence of the earth's gnetism, will cause it to become to a certain extent permanently gnetised. The distribution of the magnetism, the direction of its gnetic axis, will depend on the position in which it has been built; it y or may not coincide with the direction of the keel. The vessel comes in short a huge magnet, and will exert an influence of its own

upon the compass quite independently of vertical or horizontal
This influence is *semicircular*, that is, it disappears when the
axis of the ship is in the magnetic meridian and is greates
angles to it. It may be compensated by two permanent magn
near the compass in suitable positions found by trial during tl
of swinging the ship. Supposing the inherent magnetism of tl
have the power of drawing the compass a point to the east,
pensating magnets may be so arranged as to tend to draw it a
the west, and thus keep it in the magnetic meridian. If, ho
inherent magnetism be destroyed, from whatever cause, it is
the magnets will now draw it aside a point too much to the w
is the source of a new difficulty. It has been found that a s
at the time of sailing was properly compensated would on
from a long voyage have its compasses over-compensated. The
which the ship had experienced had destroyed its inherent m
and numerous instances are known where the loss of a vess
directly traced to this cause. Fortunately, it has been found
some time a ship's magnetic condition is virtually permanen
unaltered by any further wear and tear. The magnetism whic
retains is called its *permanent* magnetism, in opposition to th
manent which it loses.

The difficulty of adequately compensating compasses, which
increased by the armour-plated and turret ships now in use, ha
one school to throw over any attempt at correction; but l
observation of the magnetic condition of a ship, and tabul
errors to construct a table, by comparing which with the indi
the compass at any one time, the true course can be made out.

In the Royal Navy, the plan now adopted is to combine both
compensate the errors to a considerable extent, and then co
table of the residual errors.

661. **Saturation.**—Experiment has shown that to a certa
the magnetic force which can be imparted to a bar or needle
with the power of the magnets used. But there is a limit to
netic force which can be imparted to a bar or needle, and wh
attained, the bar is said to be *saturated* or *magnetised to satur*
bar may indeed be magnetised beyond this point, but this is n
nent; it gradually diminishes until it has sunk to the point of s

This is readily intelligible, for the magnetisms once separate
reunite, and when their attractive force is equal to that which
their saturation, that is, the coercive force of the metal, equil
attained, and the magnet is saturated. Hence, more magneti
to be developed in bars than they can retain, in order that
decline to their permanent state of saturation. To increase th
ism of an unsaturated bar, a less feeble magnet must not be
that by which it was originally magnetised.

662. **Magnetic battery.**—A *magnetic battery* or *magazine* c
a number of magnets joined together by their similar poles. S
they have the form of a horse-shoe, and sometimes a rectilin

epresented in fig. 522 consists of five superposed steel plates 23 consists of twelve plates, arranged in three layers of four horse shoe form is best supporting a weight, for les are used at once. In s are magnetised separ- en fixed by screws.

of a battery is not equal the forces of each bar, repulsive action exerted on the adjacent ones. increased by making the 1 or 2 centimetres shorter in the middle (fig. 522).

tures. — When even a at its limit of saturation, oses its magnetism. To *armatures* or *keepers* are are pieces of soft iron, A 523), which are placed in the poles. Acted on they become powerful agnets, possessing oppo- to that of the inducing s react in turn on the permanent magnetism of the bars, d even increasing it.

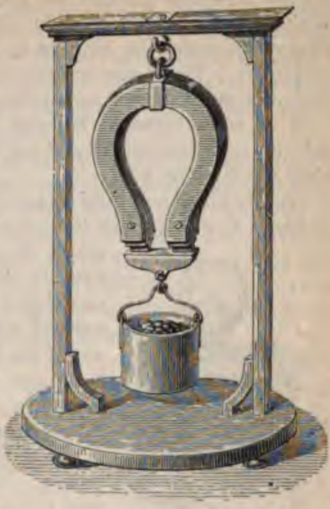


Fig. 522.

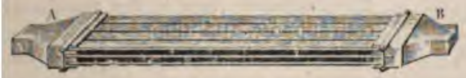


Fig. 523.

nagnets are in the form of bars, they are arranged in pairs, g. 524, with opposite poles in juxtaposition, and the circuit by two small bars of soft iron, AB. Moveable magnetic pontaneously towards the magnetic poles of the earth, the hich acts as a keeper.

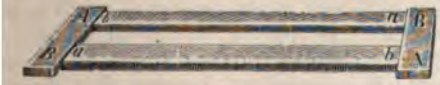


Fig. 524.

oe magnet has a keeper attached to it, which is usually is to support a weight. The keeper becomes magnetised luence of the two poles, and adheres with great force; the it can support being much more than double that which a ould hold.

to this weight, a singular and hitherto inexplicable phenomenon has been observed. When contact is once made, and the keeper is charged with its maximum weight, any further addition would detach it; but if left in contact for a day, an additional weight may be added without detaching it, and by slightly increasing the weight every day, it may ultimately be brought to support a far greater load than it would originally. But if contact be once broken, the weight it can now support does not much exceed its original charge.

It is advantageous that the surfaces of the magnet and armatures which are in contact should not be plane, but slightly cylindrical, so that they touch along a line.

In providing a natural magnet with a keeper, the line joining the two poles is first approximately determined by means of iron filings. Two plates of soft iron (fig. 525), each terminating in a massive shoe, are then applied to the faces corresponding to the poles. Under the influence of the natural magnet, these plates become magnetised, and if the letters A and B represent the position of the poles of the natural magnet, the poles of the armature are *a* and *b*. These armatures, once magnetised, react on the neutral fluid of the natural magnet, decomposing it, and increasing its natural power. Without armatures, natural magnets are very feeble, but armed they can support a weight that gradually increases to a certain limit, which they cannot exceed.

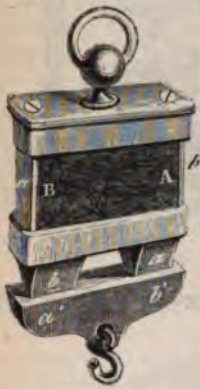


Fig. 525.

664. **Portative Force. Power of magnets.**—The *portative force* is the weight which a magnet can support, and numerous experiments have been made upon it by Häcker. He found the portative force of a saturated horse-shoe magnet, which, by repeatedly detaching the keeper, has become constant, may be represented by the formula

$$P = a\sqrt[3]{p^2},$$

in which P is the portative force of the magnet, p its own weight, and a a coefficient, which varies with the nature of the steel and the mode of magnetising. It follows from this that a magnet which weighs 1,000 ounces only supports 25 times as much as one weighing 8 ounces or as heavy, and 125 such bars would support as much as one which is as heavy as all together. It appears immaterial whether the section of the bar is quadratic or circular, and the distance of the legs is of inconsiderable moment; it is important, however, that the magnet be suspended vertically, and that the load be exactly in the middle. In Häcker's magnets the value of a was 10·33, while in Logemann's it was 23.

The strength of two bar magnets may be compared by the follow simple method, which is known as Külp's *compensation method*:—A s magnetic compass needle is placed in the magnetic meridian. One of one of the magnets to be tested is then placed at right angles to magnetic meridian in the same plane as the needle, and so that its axis prolonged would bisect the needle. The compass needle is thereby deflected through a certain angle. The similar pole of the other magnet is then placed similarly on the other side of the needle, and a position found for it in which it exactly neutralises the action of the first magnet, that is, when the needle is again in the magnetic meridian. The strengths of the two magnets are then approximately as the cubes of the distance of the acting poles from the magnetic needle.

665. **Circumstances which influence the power of magnets.**—All bars do not attain the same state of saturation, for their coercive force varies. Twisting or hammering imparts to iron or steel a considerable coercive force. But the most powerful of these influences is the *operation of tempering* (89). Coulomb found that a steel bar tempered at dull redness, and magnetised to saturation, made ten oscillations in 93 seconds. The same bar tempered at a cherry-red heat, and similarly magnetised to saturation, only took 63 seconds to make ten oscillations.

Hence, the harder the steel the greater is its coercive force ; it receives magnetism with much greater difficulty, but retains it more effectually. Very hard steel bars have, however, the disadvantage of being very brittle, and in the case of long thin bars, a hard tempering is apt to produce consequent points. Compass needles are usually tempered at the blue heat, that is, about 300° C., by which a high coercive force is obtained without great fragility.

Temperature.—Increase of temperature always produces a diminution of magnetic force. If the changes of temperature are small, those of the atmosphere for instance, the magnet is not permanently altered. Kupfer allowed a magnet to oscillate at different temperatures, and found a definite decrease in its power with increased temperature, as indicated by its slower oscillations. In the case of a magnet 2½ inches in length, he observed that with an increase of each degree of temperature the duration of 800 oscillations was 0·4″ longer. If n be the number of oscillations at zero, and n the number at t, then

$$n_1 = n\,(1 - ct),$$

where c is a constant depending in each case on the magnet used. This formula has an important application in the correction of the observations of magnetic intensity which are made at different places and at different temperatures, and which, in order to be comparable, must first be reduced to a uniform temperature.

When a magnet has been more strongly heated, it does not regain its original force on cooling to its original temperature, and when it has been heated to redness, it is demagnetized. This was first shown by Coulomb, who took a saturated magnet, and progressively heated it to higher temperatures, and observed the number of oscillations after each heating. The higher the temperature to which it had been heated the slower its oscillations.

A magnet heated to bright redness loses its magnetism so completely that it is quite indifferent, not only towards iron, but also towards another

magnet. Incandescent iron also does not possess the propert
attracted by the magnet. Hence there is in the case of iron a
limit, beyond which it is unaffected by magnetism. Such a
limit exists in the case of other magnetic metals. With
instance, it is far beyond a white heat, for at the highest tem
hitherto examined it is still magnetic ; the magnetic limit of *ch*
somewhat below red heat ; that of *nickel* at about 350° C., and
nese at about 15° to 20° C.

Torsion.—Torsion exerts a great influence on the magnet
a bar, and the interesting phenomenon has been observed
sion influences magnetism in the same manner as magnet
torsion. Thus the permanent magnetism of a steel bar is dimi
torsion, but not proportionally to the increase of torsion. In lik
the torsion of twisted iron wires is diminished by their being m
though less so than in proportion to their magnetisation.
torsions in the same direction scarcely diminish magnetisati
torsion in the opposite direction produces a new diminuti
magnetism. In a perfectly analogous manner, repeated magn
in the same sense scarcely diminish torsion, but a renewed mag
in the opposite direction does so.

666. **Distribution of free magnetism.**—Applying his metho
lations, Coulomb investigated the distribution of magnetic force
ent parts of a magnet. He placed a large magnet in a vertica
in the magnetic meridian ; he then took a small magnetic n
pended by a thread without torsion, and, having ascertained th
of its oscillations under the influence of the earth's magnetism
presented it to different parts of the magnet. The oscillat
fewer as the needle was nearer the middle of the bar, and when
reached that position, their number was the same as under the
of the earth's magnetism alone. He found that with saturate
more than 7 inches in length the distribution could always be
by a curve whose abscissæ were the distances from the en
magnet, and whose ordinates were the force of magnetism
points.

With magnets of the above dimensions the poles are at the
tance from the end ; Coulomb found the distance to be 1·6 in
bar 8 inches long. The same physicist found that, with shorte
distance of the poles from the end is $\frac{1}{6}$ of the length ; thus wit
three inches it would be half an inch.

These results presume that the other dimensions of the bar
small as compared with its length, that it has a regular sha
uniformly magnetised. When these conditions are not ful
positions of the poles can only be determined by direct tria
magnetic needle. With lozenge-shaped magnets the poles are
middle.

Coulomb found that these lozenge-shaped bars have a greater
force than rectangular bars of the same weight, thickness, and

Noad, Students text book of E [Phy 4027.30]
Jenkins E and Mag. [Phy 4023.14]
Stanwell. Man. of E [Phy 4027.16]
Maxwell Elec + Mag [4026.]

BOOK IX.

FRICTIONAL ELECTRICITY.

CHAPTER I.

FUNDAMENTAL PRINCIPLES.

667. **Electricity. Its nature.**—Electricity is a powerful physical agent which manifests itself mainly by attractions and repulsions, but also by luminous and heating effects, by violent commotions, by chemical decompositions, and many other phenomena. Unlike gravity, it is not inherent in bodies, but is evoked in them by a variety of causes, among which are friction, pressure, chemical action, heat, and magnetism.

Thales, six centuries before Christ, knew that when *amber* was rubbed with silk, it acquired the property of attracting light bodies: and from the Greek form of this word (ἤλεκτρον, *electron*) the term *electricity* has been derived. This is nearly all the knowledge left by the ancients; and it was not until towards the end of the sixteenth century that Dr. Gilbert, physician to Queen Elizabeth, showed that this property was not limited to amber, but that other bodies, such as sulphur, wax, glass, etc., also possessed it in a greater or less degree.

668. **Development of electricity by friction.**—When a glass rod, or a stick of sealing-wax, or shellac, is held in the hand, and rubbed with a piece of flannel or with the skin of a cat, the parts rubbed will be found to have the property of attracting light bodies, such as pieces of silk, wool, feathers, paper, bran, gold leaf, etc., which, after remaining a short time in contact, are again repelled. In order to ascertain whether bodies are electrified or not, instruments called *electroscopes* are used. The simplest of these, the *electric pendulum* (fig. 526), consists of a pith ball attached by means of a silk thread to a glass support. When an electrified body is brought near the pith ball, the latter is instantly attracted, but after momentary contact is again repelled (fig. 527).

A solid body may also be electrified by friction with a liquid or with a gas. In the Toricellian vacuum a movement of the mercury against the sides of the glass produces a disengagement of electric light visible in the dark; a tube exhausted of air, but containing a few drops of mercury, becomes also luminous when agitated in the dark.

If a quantity of mercury in a dry glass vessel be connected with a gold-leaf electroscope by a wire, and a dry glass rod be immersed in it, no indications are observed during the immersion, but on withdrawing the rod, the leaves increasingly diverge, attaining their maximum when the rod leaves the mercury.

Some substances, particularly metals, do not seem capable of receiving the electric excitement. When a rod of metal is held in the hand, and rubbed with silk or flannel, no electrical effects are produced in it; and

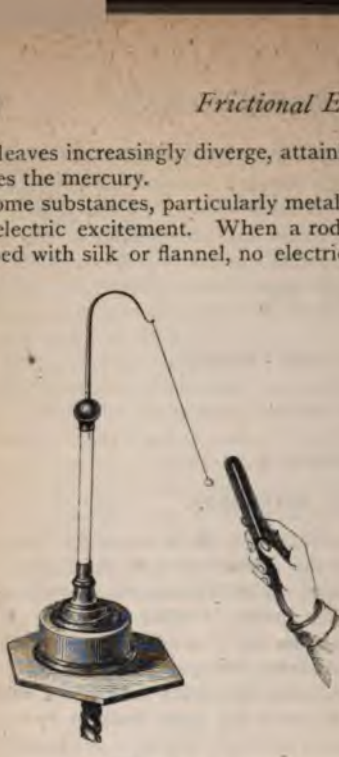


Fig. 526.

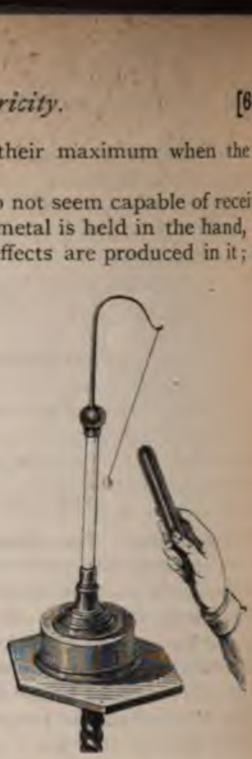


Fig. 527.

bodies were formerly divided into *ideoelectrics*, or those which become electrical by friction, and *anelectrics*, or those which do not possess this property. These distinctions no longer obtain in any absolute sense; it will presently be seen that, under appropriate conditions, all bodies may be electrified by friction (670).

With reference to the cause of the production of electricity by friction nothing is known. Wollaston attributed it to oxidation; but Wilson and Gray have shown that electrical phenomena may be produced in vacuo, and Gay-Lussac proved that electricity may be developed in an atmosphere of carbonic acid.

669. **Conductors and nonconductors.**—When a glass rod, rubbed at one end, is brought near an electroscope, that part only will be electrified which has been rubbed; the other end will produce neither attraction nor repulsion. The same is the case with a rod of shellac or of sealing-wax. In these bodies electricity does not pass from one part to another—they do not *conduct* electricity. Experiment shows, that when a metal has received electricity in any of its parts, the electricity instantly spreads throughout its entire surface. Metals are hence said to be good *conductors* of electricity.

Bodies have, accordingly, been divided into *conductors* and *nonconductors*. This distinction is not absolute, and we may advantageously consider bodies as offering a resistance to the passage of electricity which varies with the nature of the substance. Those bodies which offer little e are then conductors, and those which offer great resistance are uctors or insulators : electrical *conductivity* is thus the inverse of *resistance.* We are to consider that between conductors and uctors there is a *quantitative* and not a *qualitative* difference ; no conductor so good but that it offers some resistance to the of electricity, nor is there any substance which insulates so ly but that it allows some electricity to pass. The transition ductors to nonconductors is gradual, and no line of sharp de- n can be drawn between them.

s sense we are to understand the following table, in which bodies sed as *conductors, semiconductors,* and *nonconductors*; those eing conveniently designated as conductors which when applied rged electroscope discharge it almost instantaneously ; semicon- being those which discharge it in a short but measurable time, a nds, for instance; while nonconductors effect no discharge in the f a minute.

ductors.	*Semiconductors.*	*Nonconductors.*
	Alcohol and ether.	Dry oxides.
rnt charcoal.	Powdered glass.	Ice at -25° C.
:.	Flour of sulphur.	Lime.
	Dry wood.	Lycopodium.
solutions.	Paper.	Caoutchouc.
	Ice at 0°.	Air and dry gases.
		Dry paper.
les.		Silk.
.		Diamond and precious stones.
salts.		Glass.
		Wax.
		Sulphur.
		Resins.
		Amber.
		Shellac.

t is arranged in the order of decreasing conductivity, or what is e thing, of increasing resistance. The arrangement is not in- however. Conductivity depends on many physical conditions. r example, which does not conduct at any ordinary temperatures, s very well at a red heat. Shellac and resin do not conduct so n they are heated. Water, which is a good conductor, conducts e in the state of ice at 0°, and very badly at -25°. Powdered d flour of sulphur conduct very well, while in large masses they onductors ; probably because in a state of powder each particle covered with a film of moisture that acts as a conductor.

ding to Said Effendi, if the conducting power of water be taken the conducting power of petroleum is 72 ; alcohol 49 ; ether 40; ne 23 : and benzole 16.

nsulating bodies. Common reservoir.—Bad conductors are *nsulators*, for they are used as supports for bodies in which elec- to be retained. A conductor remains electrified only so long as it is surrounded by insulators. If this were not the case, as soon as the electrified body came in contact with the earth, which is a good conductor, the electricity would pass into the earth, and diffuse itself through its whole extent. On this account, the earth has been named the *common reservoir*. A body is insulated, by being placed on a support with glass feet, or on a resinous cake, or by being suspended by silk threads. No bodies, however, insulate perfectly; all electrified bodies lose their electricity more or less rapidly by means of the supports on which they rest. Glass is always somewhat hygroscopic, and the aqueous vapour which condenses on it affords a passage for the electricity; the insulating power of glass is materially improved by coating it with shellac or copal varnish. Dry air is a good insulator, but when the air contains moisture, it conducts electricity, and this is the principal source of the loss of electricity. Hence it is necessary in electrical experiments, to rub the supports with cloths dried at the fire, and to surround electrified bodies by glass vessels, containing substances which attract moisture, such as chloride of calcium.

It is from their great conductivity, that metals do not become electrified by friction. But if they are insulated, and then rubbed, they give good indications. This may be seen by the following experiment (fig. 528). A brass tube is provided with a glass handle, by which it is held, and then rubbed with silk or flannel. On approaching the metal to the pendulum, the pith ball will be attracted. If the metal is held in the hand electricity is indeed produced by friction—but it immediately passes through the body into the ground.

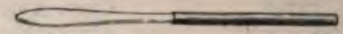


Fig. 528

If, too, the cap of a gold-leaf electroscope be briskly flapped with a dry silk handkerchief, the gold leaves will diverge.

671. **Distinction of the two kinds of electricity.**—If electricity be developed on a glass rod by friction with silk, and the rod be brought near an electrical pendulum (fig. 527), the ball will be attracted to the glass, and after momentary contact will be again repelled. By this contact the ball becomes electrified, and so long as the two bodies retain their electricity, repulsion follows when they are brought near each other. If a stick of sealing-wax, electrified by friction with flannel or skin, be approached to another electrical pendulum, the same effects will be produced, the ball will fly towards the wax, and after contact will be repelled. Two bodies, which have been charged with electricity, repel one another. But the electricities, respectively developed in the preceding cases, are not the same. If, after the pith ball had been touched with an electrified glass rod, an electrified stick of sealing-wax, and then an electrified glass rod, be alternately approached to it, the pith ball will be *attracted* by the former and *repelled* by the latter. Similarly, if the pendulum be charged by contact with the electrified sealing-wax, it will be *repelled* when this is approached to it, but *attracted* by the approach of the excited glass rod.

On experiments of this nature, Dufay first made the observation that there are two different electricities: the one developed by the friction of glass, the other by the friction of resin or shellac. To the first the name *vitreous* electricity is given; to the second the name *resinous* electricity.

672. **Theories of electricity.**—Two theories have been proposed to account for these different effects of electricity. Franklin supposed that there exists a peculiar, subtle, imponderable fluid, which acts by repulsion on its own particles, and pervades all matter. This fluid is present in every substance in a quantity peculiar to it, and when it contains this quantity, it is in the natural state, or in a state of equilibrium. By friction, certain bodies acquire an additional quantity of the fluid, and are said to be *positively* electrified: others, by friction, lose a portion, and are said to be *negatively* electrified. The former state corresponds to *vitreous* electricity, and the latter to *resinous* electricity. Positive electricity is represented by the sign +, and negative electricity by the sign −; a designation based on the algebraical principle, that when a plus quantity is added to an equal minus quantity zero is produced. So when a body containing a quantity of positive electricity is touched with a body possessing an equivalent quantity of negative electricity, a neutral or zero state is produced.

The *theory of Symmer*, which is now generally admitted, explains in a satisfactory manner most electrical phenomena. But it is only an hypothesis, and must not be accepted as expressing anything absolute.

Symmer's theory assumes that every substance contains an indefinite quantity of a subtle imponderable matter, which is called the electrical fluid. This fluid is formed by the union of two fluids—the *positive* and he *negative*. When they are combined they neutralise one another, and he body is then in the natural or neutral state. By friction, and by several other means, the two fluids may be separated, but one of them can never be excited without a simultaneous production of the other. There may, however, be a greater or less excess of the one or the other in any body, and it is then said to be electrified *positively* or *negatively*. As in Franklin's theory, *vitreous* corresponds to *positive*, and *resinous* to *negative* electricity. This distinction is merely conventional: it is adopted or the sake of convenience, and there is no other reason why resinous lectricity should not be called positive electricity.

Fluids of the same name repel one another, and fluids of opposite kinds ttract each other. The fluids can circulate freely on the surface of certain bodies, which are called conductors, but remain confined to certain arts of others, which are called nonconductors.

As has been already said, this theory is quite hypothetical; but its eneral adoption is justified by the convenient explanation which it gives f electrical phenomena.

673. **Action of electrified bodies on each other.**—Admitting the two-uid hypothesis, the phenomena of attraction and repulsion may be nunciated in the following law, which is the basis of all the theories of rictional electricity:

Two bodies charged with the same electricity repel each other; two bodies charged with opposite electricities attract each other.

These attractions and repulsions take place in virtue of the action which the two electricities exert on themselves, and not in virtue of their action on the particles of matter.

674. **Law of the development of electricity by friction.**—Whenever two bodies are rubbed together, the neutral fluid is decomposed. Two electricities are developed at the same time and in equal quantities—one body takes the positive, and the other the negative fluid. This may be proved by the following simple experiment devised by Faraday:—A small flannel cap provided with a silk thread is fitted on the end of a stout rod of shellac, and rubbed round a few times. When the cap is removed by means of a silk thread, and presented to a pith-ball pendulum charged with positive electricity, the latter will be repelled, proving that the flannel is charged with positive electricity; while, if the shellac is presented to the pith ball, it will be attracted, showing that the shellac is charged with negative electricity. Both electricities are present in equal quantities; for if the rod be presented to the electroscope before removing the cap, no action is observed.

The electricity developed on a body by friction depends on the rubber as well as the body rubbed. Thus glass becomes negatively electrified when rubbed with cat's skin, but positively when rubbed with silk. In the following list the substances are arranged in such an order that each becomes positively electrified when rubbed with any of the bodies following, but negatively when rubbed with any of those which precede it:—

1. Cat's skin.
2. Flannel.
3. Ivory.
4. Rock crystal.
5. Glass.
6. Cotton.
7. Silk.
8. The hand.
9. Wood.
10. Metals.
11. Caoutchouc.
12. Sealing-wax.
13. Resin.
14. Sulphur.
15. Gutta percha.
16. Gun-cotton.

The nature of the electricity set free by the friction depends also on the degree of polish, the direction of the friction, and the temperature. If two glass discs of different degrees of polish are rubbed against each other, that which is most polished is positively, and that which is least polished is negatively electrified. If two silk ribbons of the same kind are rubbed across each other, that which is transversely rubbed is negatively, and the other positively electrified. If two bodies of the same substance, and of the same polish, but of different temperatures, are rubbed together, that which is most heated is negatively electrified. Generally speaking, the particles which are most readily displaced are negatively electrified.

675. **Development of electricity by pressure and cleavage.**—Electrical excitement may be produced by other causes than friction. If a disc of wood, covered with oiled silk, and a metal disc, both provided

with insulating handles, be pressed together, and then suddenly separated, the metal disc is negatively electrified. A crystal of Iceland spar pressed between the fingers becomes positively electrified, and retains this state for some time. The same property is observed in several other minerals, even though conductors, provided they be insulated. If cork and caoutchouc be pressed together, the first becomes positively, and the other negatively electrified. A disc of wood pressed on an orange and separated, carries away a good charge of electricity, if the contact be rapidly interrupted. But if the disc is slowly removed the quantity is smaller, for the two fluids recombine at the moment of their separation. For this reason there is no apparent effect when the two bodies pressed together are good conductors.

Becquerel has also observed that cleavage is a source of electricity. If a plate of mica be rapidly split in the dark, a slight phosphorescence is perceived. Becquerel fixed glass handles to each side of the plate of mica, and then rapidly separated them. On presenting each of the plates thus separated to an electroscope, he found that one was negatively and the other positively electrified.

Laminated mica, and all badly conducting crystalline substances, exhibit electrical indications by cleavage. The separated plates are always in opposite electrical conditions, provided they are not good conductors: for if they were, the separation would not be sufficiently rapid to prevent the recombination of the two electricities. To the phenomena here described is due the luminous appearance seen in the dark when sugar is broken.

676. **Pyroelectricity.**—Certain minerals, when warmed, acquire elecrical properties; a phenomenon to which the name *pyroelectricity* is given. It is best studied in *tourmaline*, in which it was first discovered, rom the fact that this mineral had the power of first attracting and then epelling hot ashes when placed among them.

To observe this phenomenon, a crystal of tourmaline is balanced by a silk thread, in a glass cylinder placed on a heated metal plate. On subequently investigating the electric condition of the ends by approaching o them successively an electrified glass rod, one end will be found to be ositively electrified, and the other end negatively electrified, and each nd shows this polarity as long as the temperature rises. The arrangement of the electricity is thus like that of the magnetism in a magnet. he points at which the intensity of free electricity is greatest are called e *poles*, and the line connecting them is the *electric axis*. When a urmaline, while thus electrified, is broken in the middle, each of the eces has its two poles.

These polar properties depend on the *change* of temperature. When tourmaline, which has become electrical by being warmed, is allowed cool regularly, it first loses electricity, and then its polarity becomes versed; that is, the end which was positive now becomes negative, and at which was negative becomes positive, and the position of the poles w remains unchanged so long as the temperature sinks. Tourmaline ly becomes pyroelectric within certain limits of temperature; these vary somewhat with the length, but are usually between 10° and 150° C. Below and above these temperatures it behaves like any other body, and shows no polarity.

The name *analogous* pole is given to that end of the crystal which shows positive electricity when the temperature is rising, and negative electricity when it is sinking: *antilogous* pole to that end which becomes negative by being heated, and positive by being cooled.

The phenomena of pyroelectricity are intimately connected with the crystalline form of the mineral; and are only seen in those crystals whose forms are *hemihedral*, or which are differently modified at the ends of their crystallographical principal axis.

Besides tourmaline the following minerals are found to be pyroelectric: boracite, topaz, prehnite, silicate of zinc, scolezite, axenite. And the following organic bodies are pyroelectric: cane-sugar, Pasteur's salt (racemate of sodium and ammonium), tartrate of potassium, &c.

CHAPTER II.

QUANTITATIVE LAWS OF ELECTRICAL ACTION.

677. **Laws of electrical attractions and repulsions.**—The laws which regulate the attractions and repulsions of electrified bodies may be thus stated:—

I. *The repulsions or attractions between two electrified bodies are in the inverse ratio of the squares of their distance.*

II. *The distance remaining the same, the force of attraction or repulsion between two electrified bodies is directly as the product of the quantities of electricity with which they are charged.*

These laws were established by Coulomb, by means of the torsion balance, used in determining the laws of magnetic attractions and repulsions (652), modified in accordance with the requirements of the case. The wire, on the torsion of which the method depends, is so fine that a foot weighs only $\frac{1}{10}$ of a grain. At its lower extremity there is a fine shellac thread, *n o* (fig. 529), at one end of which is a small disc of copper foil, *n*. Instead of the vertical magnetic needle there is a glass rod, *i*, terminated by a gil pith ball, *m*, which passes through the aperture *r*. The scale is fixe round the sides of the vessel, and during the experiment the ball *m* is

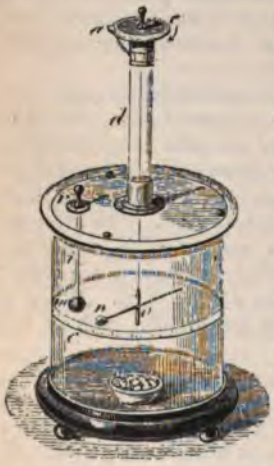


Fig. 529.

posite the zero point. The micrometer consists of a small graduated ic, *e*, moveable independently of the tube, *d*, and of a fixed index, *a*, iich shows by how many degrees the disc is turned. In the centre of disc there is a small button, to which is fixed the wire which suprts *n o*.

. The micrometer is moved until the zero point is opposite the index, l the tube *d* is turned until the knob *n* is opposite zero of the graduated cle: the knob *m* is in the same position, and thus presses against *n*. e knob *m* is then removed and electrified, and replaced in the appaus, through the aperture *r*. As soon as the electrified knob *m* touches the latter becomes electrified, and is repelled, and after a few oscilions remains constant at a distance at which the force of repulsion is ıal to the force of torsion. In a special experiment Coulomb found the gle of torsion between the two to be 36°; and as the force of torsion is portional to the angle of torsion, this angle represents the repulsive ce between *m* and *n*. In order to reduce the angle to 18° it was cessary to turn the disc through 126°. The wire was twisted 126° in the ection of the arrow at its upper extremity, and 18° in the opposite ection at its lower extremity, and hence there was a total torsion of 4°. On moving the micrometer in the same direction, until the angle deviation was 8½°, 567° of torsion were necessary. Hence the whole rsion was 575½°. Without sensible error these angles of deviation may taken at 36°, 18°, and 9°, and on comparing them with the correspondg angles of torsion 36°, 144°, and 576°, we see that while the first are as

$$1 : \tfrac{1}{2} : \tfrac{1}{4},$$

latter are as

$$1 : 4 : 16;$$

it is, that for a distance ½ as great, the angle of torsion is 4 times as at, and that for a distance ¼ as great the repulsive force is 16 times great.

In experimenting with this apparatus, the air must be thoroughly dry, order to diminish, as far as possible, loss of electricity. This is ected by placing in it a small dish containing chloride of calcium.

The experiments by which the law of attraction is proved are made in ch the same manner, but the two balls are charged with opposite ctricities. A certain quantity of electricity is imparted to the movee ball, by means of an insulated pin, and the micrometer moved until re is a certain angle below. A charge of electricity of the opposite id is then imparted to the fixed ball. The two balls tend to move gether, but are prevented by the torsion of the wire, and the moveable ll remains at a distance at which there is equilibrium between the ce of attraction, which draws the balls together, and that of torsion, ıich tends to separate them. The micrometer screw is then removed a greater distance, by which more torsion and a greater angle between e two balls are produced. And it is from the relation which exists tween the angle of deflection on the one hand, and the angle which presses the force of torsion on the other, that the law of attraction has een deduced.

ii. To prove this second law let a charge be imparted to *m*; *n* being in contact with it becomes charged and is repelled to a certain distance. The angle of deflection being noted, let the ball *m* be touched by an insulated but unelectrified ball of exactly the same size and kind; in this way half its charge is removed, and the angle of deflection will now be found to be only half its original amount. In like manner if either *m* or the moveable body be now again deprived of half its electricity, the deflection will be a quarter of what it originally was, and so on.

The two laws are included in the formula $F = \frac{ee'}{d^2}$, where F is the force; e and e' the quantities of electricity on any two surfaces, and d the distance between them.

678. **Distribution of electricity.**—When an insulated sphere of conducting material is charged with electricity, the electric fluid passes to the surface of the sphere, and forms an extremely thin layer. If, in Coulomb's balance, the fixed ball be replaced by another electrified sphere, a certain repulsion will be observed. If then this sphere be touched with an insulated sphere identical with the first, but in the natural state, the first ball will be found to have lost half its electricity, and only half the repulsion will be observed. By repeating this experiment with spheres of various substances, solid and hollow, but all having the same superficies, the result will be the same, excepting that with imperfectly conducting materials, the time required for the distribution will be greater. From this it is concluded that the distribution of electricity depends on the extent of the surface, and not on the mass, and, therefore, that electricity does not penetrate into the interior, but is confined to the surface. This conclusion is further established by the following experiments :—

i. A thin hollow copper sphere provided with an aperture of about an inch (fig. 530), and placed on an insulating support, is charged in the interior with electricity. When the *carrier* or *proof plane* (a small disc of copper foil at the end of a slender glass or shellac rod) is applied to the interior, and then brought near an electroscope, no electrical indications are produced. But if the proof plane is applied to the electroscope after having been in contact with the exterior, a considerable divergence ensues.

ii. A hollow globe, fixed on an insulating support, is provided with two hemispherical envelopes which fit closely, and can be separated by glass handles. The interior is now electrified, and the two hemispheres brought in contact. On then rapidly removing them (fig. 531)

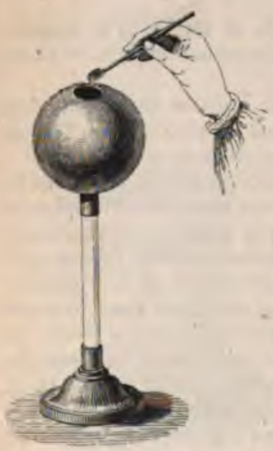


Fig. 530.

e coverings will be found to be electrified, while the sphere is in its tural condition.

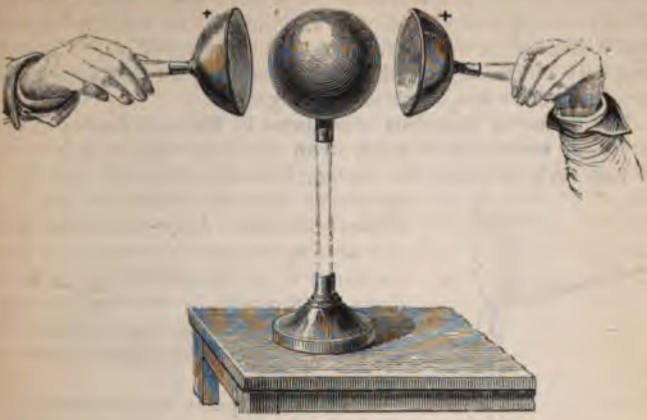


Fig. 531.

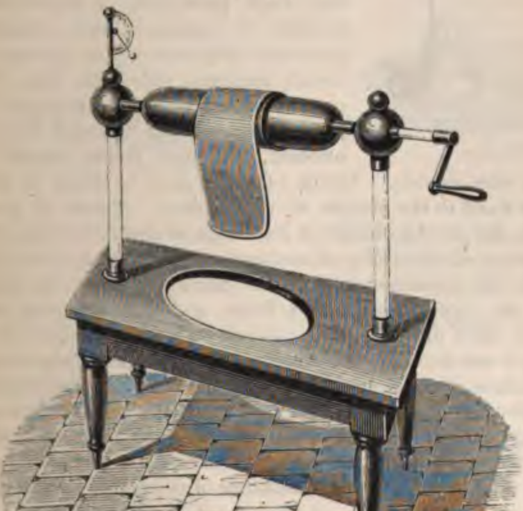


Fig. 532.

iii. The distribution of electricity on the surface may also be shown by eans of the following apparatus. It consists of a metallic cylinder on sulated supports, on which is fixed a long strip of tin foil which can be rolled up by means of a small insulating handle (fig. 532). A q electrometer is fitted in metallic communication with the cylinder. the sphere is rolled up, a charge is imparted to the cylinder, by certain divergence is produced. On unrolling the tin foil, this div gradually diminishes, and increases as it is again rolled up. The q of electricity remaining the same, the electrical force, on each surface, is therefore less as the surface is greater.

iv. The following ingenious experiment by Faraday further ill this law :—A metal ring is fitted on an insulated support, and a gauze bag, such as is used for catching butterflies, is fitted to it (fi By means of a silk thread, the bag drawn inside out. After electrifying t it is seen by means of a proof plane t electricity is on the exterior, but if th tions are reversed by drawing the side out, so that the interior has now the exterior, the electricity will still b on the exterior.

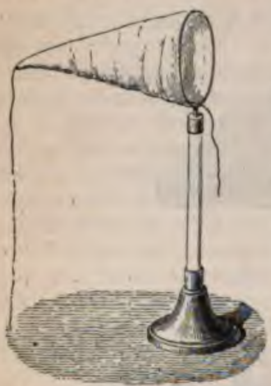


Fig. 533.

v. The same point may be furthe trated by an experiment due to Terqu bird cage, preferably of metal wire, pended by insulators, and contains gold leaf electroscope or pieces of metal, feathers, pith balls, etc. Wh cage is connected with an electrical m the articles in the interior are qu affected, although strong sparks taken from the outside. Bands of paper may be fixed to the while those fixed to the outside diverge widely. A bird in the in quite unaffected by the charge or discharge of the electricity of th

The property of electricity, of accumulating on the outside of bo ascribed to the repulsion which the particles exert on each Admitting the hypothesis of two fluids, and that opposite elec attract each other in the inverse ratio of their distances, while lik tricities repel one another, according to the same law, Poisson, by of mathematical analysis, has arrived at the same conclusion in re to the distribution of electricity on bodies as that which follows fr previous experiments. Electricity tends constantly to pass to the of bodies, where it exists in very thin layers ; it continually te escape, but is prevented by the resistance of the feebly conducting phere.

679. **Electric tension and density.**—On a metallic sphere the bution of the electrical fluid will be uniform in every part, simply f symmetry. This has been demonstrated by means of the proof and the torsion balance. A metallic sphere placed on an inst support was electrified, and touched at different parts of its surfac the proof plane, which each time was applied to the moveable nee the torsion balance. As in all cases the torsion observed was se

ıme, it was concluded that the proof plane had each time received ıme quantity of electricity. In the case of an elongated ellipsoid 34) it is found that the electrical layer has a different density at ent points of the surface. In virtue of its repulsion the electricity nulates at the most acute points, and here it has the greatest *tension* ıdency to escape. This is demonstrated by successively touching llipsoid at different parts with the proof plane, and then bringing nto the torsion balance. By this means Coulomb found that the est deflection was produced when the proof plane had been in con- vith the point *a*, and the least by contact with the middle space *e*. ıce has found by calculation that the tension at each point is *pro- ınal to the square of the thickness of the electric layer*. The *electric*

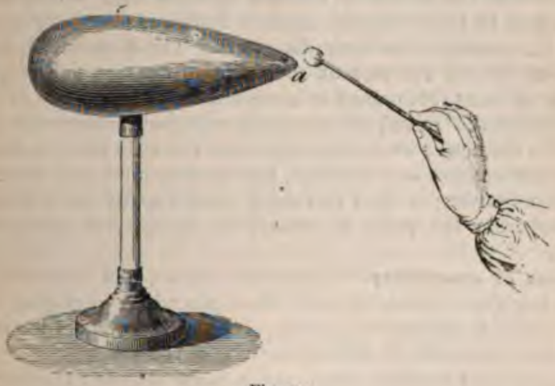


Fig. 534.

y or *electric thickness* is the term used to express the quantity of ound at any moment on a given surface. If *s* represents the surface the quantity of electricity on that surface, then, assuming that the icity is equally distributed, its electrical density is equal to $\frac{Q}{s}$.

ılomb found, by quantitative experiments, that in an ellipsoid the y of the electricity at the equator of the ellipsoid is to that at the in the same ratio as the length of the minor to the major axis. On ulated cylinder, terminated by two hemispheres, the density of the cal layer at the ends is greater than in the middle. In one case, tio of the two densities was found to be as 2·3 : 1. On a circular ıe density is greatest at the edges.

. **Power of points.**—On a sphere, the electric density is everywhere m; the further a body is removed from the shape of a sphere, the irregular is its accumulation. A pointed rod may be regarded as ıngated ellipsoid, and hence, at its extremity, the electric density e greatest. But the tension is proportional to the square of the ty; and hence the greater the density the greater will be its power ercoming the resistance of the air, and escaping. If the hand be brought near a point on an electrified conductor a slight wind is felt; and if the disengagement of electricity takes place in the dark a luminous brush is seen. In electrical apparatus, and experiments, frequent use is made of this property of points.

681. **Communication and distribution of electricity on bodies in contact.**—If two conducting bodies, one electrified and the other in the natural state, be brought into contact, the electricity will be equally distributed over the two: the one will lose and the other gain a quantity of electricity proportional to its surface. If the bodies are not conductors, there will only be loss and gain at the points in contact.

By means of the proof plane and the torsion balance, Coulomb made numerous determinations of the distribution of electricity on bodies in contact. When two insulated metallic spheres were placed in contact and electrified, he found that the electric fluid was unequally distributed, and that in proportion to their diameters. The diameters being equal, the electrical density was zero at the point of contact, and only became sensible at 23° from this point; it increased rapidly from 20° to 30°, then more slowly from 60° to 90°, and was almost constant between 60° and 180°.

When the diameters were unequal, and in the ratio of 2 : 1, the density of the point of contact was still zero, but at first increased most rapidly on the large sphere: it then increased more rapidly on the small one, and at 180° from the point of contact its density was greatest on the small one.

682. **Loss of electricity.**—Experience shows that electrified bodies gradually lose their electricity, even when placed on insulating supports. This loss is due to two causes: firstly, to the imperfection of the insulating supports, and, secondly, to the conductivity of the air.

i. All substances conduct electricity in some degree; those which are termed insulators are simply very bad conductors. An electrified conductor resting on supports must, therefore, lose a certain quantity of its electricity.

ii. The loss by the atmosphere varies with the electric tension, with the rapidity with which the air is renewed, and with the hygrometric state.

Dry air is a very imperfect conductor, but when it contains aqueous vapour, it conducts pretty well, and the more moisture it contains the better it conducts. Coulomb has attempted to show 'that in a still atmosphere, and with a constant hygrometric state, the loss for a very short space of time is directly proportional to the tension:' a law analogous to Newton's law of cooling (384).

Coulomb experimented with moist air. In perfectly dry gases, Matteucci did not find the loss of electricity in accordance with Coulomb's law. He found that within certain limits of tension, the loss was independent of the quantity of electricity, and proportional to the time; in other words, that in equal times there was an equal loss of electricity.

He further found that for equal temperatures and pressures the loss is the same in air, carbonic acid, and hydrogen, provided they are perfectly dry: at a high tension the loss of negative electricity is greater than that of positive; in dry gases, under a constant pressure, the loss increases with the temperature; and lastly, that in dry gases the loss is independent the nature of the electrified body; that is, it is the same whether it is a nductor or not.

Coulomb found not only that supports never insulate completely, but at they are the cause of an abundant loss of electricity in bodies strongly ctrified. The loss diminishes gradually, and is constant when the tenon is low. It may be neglected by giving to the supports an adequate ngth, which, according to Coulomb, must be proportional to the square the electric tension of the charged body. Brown shellac is the best sulator; glass is a hygroscopic substance, and must be dried with great are. It is best covered with a thin layer of shellac varnish, as has already een stated.

683. **Loss of electricity in vacuo.**—Inasmuch as electricity is retained n the surface of bodies by the pressure of the insulating atmosphere, hen the pressure diminishes, the loss of electricity increases, and in acuo, in which resistance is zero, all electricity escapes. This is a ecessary consequence of the mathematical theory of electricity, which ccounts for the equilibrium of electricity on the surface of bodies. But opposition to this, Hawksbee, Gray, Snow Harris, and Becquerel have bserved, that feeble electrical tensions may be retained in vacuo. Becuerel showed that in a vacuum of a millimeter a body retained a feeble arge for fifteen days. And it is probable, that if an electrified body ere in a perfect vacuum, it would retain an electrical charge, provided were sufficiently removed from any body which could exert upon it an ductive action (684).

CHAPTER III.

TION OF ELECTRIFIED BODIES ON BODIES IN THE NATURAL STATE. INDUCED ELECTRICITY. ELECTRICAL MACHINES.

684. **Electricity by influence or induction.**—An insulated conductor, arged with either kind of electricity, acts on bodies in a natural state aced near it in a manner analogous to that of the action of a magnet soft iron, that is, it decomposes the neutral fluid, attracting the oppoe and repelling the like kind of electricity. The action thus exerted said to take place by *influence* or *induction*.

The phenomena of induction may be demonstrated by means of a brass linder placed on an insulating support, and provided at its extremities th two small electric pendulums, which consist of pith balls suspended linen threads (fig. 535). If this apparatus is placed near an insulated nductor m, charged with either kind of electricity, for instance, the nductor of the electrical machine, which is charged with positive ctricity, the natural fluid of the cylinder is decomposed, free electricity ll be developed at each end, and both pendulums will diverge. If, ile they still diverge, a stick of sealing-wax, excited by friction with nnel, be approached to that end of the cylinder nearest the conductor, corresponding pith ball will be repelled, indicating that it is charged h the same kind of electricity as the sealing-wax, that is, with negative id; while if the excited sealing-wax is brought near the other ball, it will be attracted, showing that it is charged with positive electricity. If, further, a glass rod, excited by friction with silk, and therefore charged with positive electricity, be approached to the end nearest the conductor, the pendulum will be attracted; while if brought near the other end, the corresponding pendulum will be repelled. If the influence of the charged conductor be suppressed, either by removing it, or placing it in communication with the ground, the separated electricities will recombine, and the pendulums exhibit no divergence.

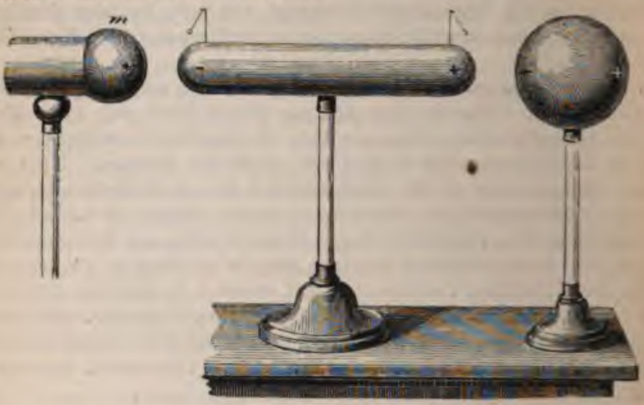


Fig. 535.

The cause of this phenomenon is obviously a decomposition of the neutral fluid of the cylinder, by the free positive electricity of the conductor, the opposite or negative electricity being attracted to that end of the cylinder nearest the conductor, while the similar electricity is repelled to the other end. Between these two extremities, there is a space destitute of free electricity. This is seen by arranging on the cylinders a series of pairs of pith balls suspended by threads. The divergence is greatest at each extremity, and there is a point at which there is no divergence at all, which is called the *neutral point*. The two fluids, although equal in quantity, are not distributed over the cylinder in a symmetrical manner; the attraction which accumulates the negative electricity at the one end is, in consequence of the greater nearness, greater than the repulsion which drives the positive electricity to the other end, and hence the neutral line is nearer one end than the other. Nor is the electricity induced at the two ends of the cylinder under the same conditions. That which is repelled to the distant extremity is free to escape if a communication be made with the ground, whilst on the other hand, the unlike electricity which is attracted is held bound or captive by the inducing action of the electrified body. Even if contact be made with the ground on the face of the cylinder adjacent to the inducing body, the electricity induced on that face will not escape. The repelled electricity however on the distant surface is not thus bound; it is free to escape by any conducting channel, and hence will immediately disappear, wherever contact be made between the

ound and the cylinder. Both the pith balls will collapse, and all signs
electricity on the cylinder depart with the escape of the repelled or free
ctricity. But now, if communication with the ground be destroyed,
d the inducing body be discharged or removed to a considerable dis-
nce, the attracted or bound electricity is itself set free, and diffusing
er the whole cylinder causes the pith balls again to diverge, but now
ith the opposite electricity to that of the original inducing body. The
ason for the escape of the repelled electricity is as follows :—If the
linder be placed in connection with the ground, by metallic contact
ith the posterior extremity, and the charged conductor be still placed
ar the anterior extremity, the conductor will exert its inductive action
before. But it is now no longer the conductor alone which is influ-
ced. It is a conductor consisting of the conductor itself, the metallic
ire, and the whole earth. The neutral line will recede indefinitely, and
nce the conductor has become infinite, the quantity of neutral fluid
composed will be increased. Hence, when the posterior extremity is
aced in contact with the ground, the pendulum at the anterior extremity
verges more widely. If the connecting rod be now removed, neither
e quantity nor the distribution will be altered ; and if the conductor
removed, or be discharged, a charge of negative electricity will be
ft on the cylinder. It will, in fact, remain charged with electricity,
e opposite of that of the charged conductor. Even if, instead of con-
cting the posterior extremity of the cylinder with the ground, any other
rt had been so connected, the general result would have been the same.
ll the parts of the cylinder would be charged with negative electricity,
d, on interrupting the communication with the earth, would remain so
arged.

Thus a body can be charged with electricity by induction as well as by
nduction. But, in the latter case, the charging body loses part of its
ctricity, which remains unchanged in the former case. The electricity
parted by conduction is of the same kind as that of the electrified
dy, while that excited by induction is of the opposite kind. To impart
ctricity by conduction, the body must be quite insulated, while in the
se of induction it must be in connection with the earth, at all events
mentaneously.

A body electrified by induction acts in turn on bodies placed near it,
parating the two fluids in a manner shown by the signs on the sphere.

What has here been said has referred to the inductive action exerted
good conductors. Bad conductors are not so easily acted upon by
luction, owing to the great resistance they present to the circulation of
ctricity, but, when once charged, the electric state is more permanent.

This is analogous to what is met with in magnetism ; a magnet in-
ntaneously evokes magnetism in a piece of soft iron, but this is only
nporary, and depends on the continued action of the magnet ; a magnet
gnetises steel with far greater diffiulty, but this magnetism is per-
nent.

685. **Limit to the action of induction.**—The inductive action which
electrified body exerts on an adjacent body in decomposing its neutral

fluid is limited. On the surface of the insulated cylinder, which we
considered in the preceding paragraph, let there be at n any small q
tity of natural electricity (fig. 536). The positive electricity of the so

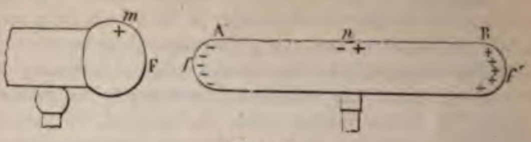


Fig. 536.

m first decomposes by induction the neutral fluid in n, attractin
negative fluid towards A, and repelling its positive towards B; but in
degree in which the extremity becomes charged with negative electri
and the extremity B with positive electricity, there are developed
and B two forces f and f', which act in the opposite direction t
original force. For the forces f and f' concur in driving towards
negative fluid of n, and towards A its positive fluid. But as the ind
force F which is exerted at m is constant, while the forces f and f
increasing, a time arrives at which the force F is balanced by the f
f and f'. All decomposition of the neutral fluid then ceases;
inducing action has attained its limit.

If the cylinder be removed from the source of electricity, as
inducing action decreases, a portion of the free fluids at A and
recombine to form the neutral fluid. If, on the other hand, they
brought nearer, as the force F now exceeds the forces f and f', a
decomposition of the neutral fluid takes place, and fresh quantitie
positive and negative fluids are respectively accumulated at A and B.

686. **Faraday's theory of induction.**—The theory of electricit
induction, as just elucidated, is the one hitherto admitted by all physic
The researches of Faraday on electric polarity tend, however, to mo
it, and may, perhaps, lead to overturn it entirely. Hitherto, the influ
of the medium, which separates the electrified from the unelectrified b
has been neglected. But Faraday's researches prove that it is in
medium that the inductive actions take place; and that the induc
action is not an action at a distance, or rather at no distance greater t
that between any two molecules. Faraday supposes that, in this medi
successions of layers become alternately positively and negatively e
trified.

The following experiment was devised by Faraday to illustrate
polarisation of the medium, as he has called it. He placed sm
filaments of silk in a vessel of turpentine, and having plunged two c
ductors in the liquid in opposite sides, he charged one and placed
other in connection with the ground. The particles of silk immediat
arranged themselves end to end, and adhered closely together, form
a continuous chain between the two sides. An experiment by Matteu
also supports Faraday's theory. He placed several thin plates of m
closely together, and provided the outside ones with metallic coatin

ulminating pane (708). Having electrified the system, the coatings emoved by insulating handles, and on examining the plates of mica sively, each was found charged with positive electricity on one side, gative electricity on the other.

the new view, the action exerted by electrified bodies on bodies in utral state, is effected by the polarisation of the alternate layers of any other medium. On the old view, the air was supposed to be passive, or at most, in virtue of its nonconductivity, to oppose a nce to the recombination of the two fluids.

ections have, nevertheless, been raised to Faraday's theory, one of st formidable of which is the action which electrified bodies exert ers at a distance even in vacuo ; unless, indeed, it be admitted that the most perfect vacuum obtainable, sufficient material molecules to produce the polarisation. In some researches which Matteucci ently made on the propagation of electricity in insulators, he has l at conclusions differing from those of Faraday.

Specific inductive capacity.—Faraday names the property which possess of transmitting the electric influence, the *inductive power.* ulating bodies do not possess it in the same degree. To determine

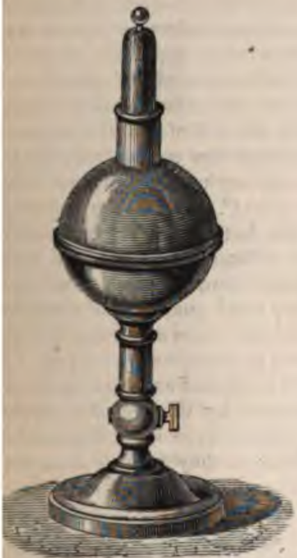


Fig. 537.

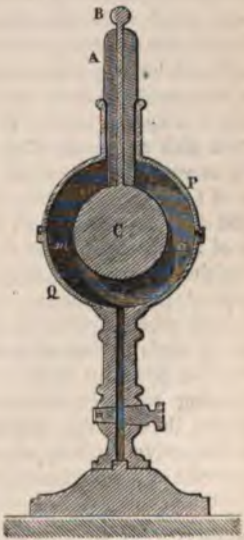


Fig. 538.

mpare the inductive power Faraday uses the apparatus represented 537, and of which fig. 538 represents a vertical section. It consists rass sphere made up of two halves, P and Q, which fit accurately ch other, like the Magdeburg hemispheres. In the interior of this spherical envelope, there is a smaller brass sphere, C, connected with a metallic rod, terminating in a ball, B. The rod is insulated from the envelope, PQ, by a thick layer of shellac, A. The space *mn* receives the substance whose inductive power is to be determined. The foot of the apparatus is provided with a screw and stopcock, so that it can be screwed on the air pump, and the air in *mn* either rarefied or exhausted.

Two such apparatus perfectly identical are used, and at first they only contain air. The envelopes PQ are connected with the ground, and the knob B of one of them receives a charge of electricity. The sphere C thus becomes charged like the inner coating of a Leyden jar (709). The layer *mn* represents the insulator which separates the two coatings. By touching B with the proof plane, which is then applied to the torsion balance, the quantity of free electricity is measured. In one experiment Faraday observed a torsion of 250°, which represented the free electricity on B. The knob B was then placed in metallic connection with the knob B′ of the other apparatus, and the torsion was now found to be 125°, showing that the electricity had become equally distributed on the two spheres, as might have been anticipated, since the pieces of apparatus were quite equal and each contained air in the space *mn*.

This experiment having been made, the space *mn* in the second apparatus was filled with the substance whose inductive power was to be determined; for example, shellac. The other apparatus, in which *mn* is filled with air, having been charged, the tension of the free electricity on C was measured. Let it be taken at 290°, the number observed by Faraday, in a special case. When the knob B of the first apparatus was connected with the knob B′ of the second, the tension was not found to be 145°, as would be expected. The apparatus containing air exhibited a tension of 114°, and that with shellac of 113°. Hence the former had lost 176°, and had retained 114°, while the latter ought to have exhibited a tension of 176° instead of 113°. The second apparatus had taken more than half the charge, and hence a larger quantity of electricity had been dissimulated by the shellac. Of the total quantity of electricity, the shellac had taken 176°, and the air 114°; hence the specific inductive capacity of air is to that of shellac as 114 : 176, or as 1 : 1·55. That is, the inductive power of shellac is more than half as great again as air.

Comparing together other substances by this general method, but varying the details, the following values have been obtained for the specific inductive capacity of *dielectrics*, as they are called in opposition to *analectrics* or conductors :—

Air	1·00	Glass	1·90
Spermaceti	1·45	Shellac	2·00
Resin	1·76	Sulphur	2·24
Pitch	1·80	India Rubber	2·80
Wax	1·86	Gutta Percha	4·00

By the following simple experiment the influence of the dielectric may be shown. At a fixed distance above a gold-leaf electroscope, let an electrified sphere be placed by which a certain divergence of the leaves produced. If now, the charges remaining the same, a disc of sulphur of shellac be interposed, the divergence increases, showing that in- ctive action takes place through the sulphur to a greater extent than ough a layer of air of the same thickness.

Faraday finds that all gases have the same inductive capacity, and that s is independent of the temperature and pressure.

In treating on induction produced by the voltaic battery, some experi- nts of Matteucci will be adduced, which show that the inductive action current electricity is independent of the nature of the insulator placed tween the inducing and the induced body, a result which, of course, es not agree with the experiments of Faraday on frictional electricity.

588. **Communication of electricity at a distance.**—In the experi- nt represented in figure 535 the opposite electricities of the conductor, d that of the separated cylinder, tend to unite, but are prevented by resistance of the air. If the tension is increased, or, if the distance of bodies be diminished, the opposed electricities at length overcome s obstacle; they rush together and combine, producing a spark, ac- mpanied by a sharp sound. The negative electricity separated on the linder, being thus neutralised by the positive electricity of the charged dy, a charge of positive electricity remains on the cylinder. The same enomenon is observed when a finger is presented to a strongly electri- d conductor. The latter decomposes by induction the neutral electri- y of the body, the opposite electricities combine with the production a spark, while the electricity of the same kind as the electrified con- ctor, which is left on the body, passes off into the ground.

The striking distance varies with the tension, the shape of the bodies, eir conducting power, and with the resistance and pressure of the inter- sed medium.

689. **Motion of electrified bodies.**—The various phenomena of at- action and repulsion which are among the most frequent manifestations electrical action may all be explained by means of the laws of induc- n. If M (fig. 539) be a fixed insulated conductor charged with posi- e electricity, and N be a moveable insulated dy, for instance, an electrical pendulum, there three cases to be considered :—

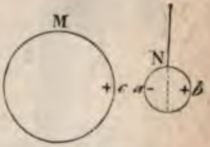


Fig. 530.

i. *The moveable body is unelectrified, and is a nductor.* In this case M acting inductively on attracts the negative and repels the positive d, so that the maximum of tension is respec- ely at the points a and b. Now a is nearer c n it is to b, and since attractions and repulsions are inversely as the are of the distance, the attraction between a and c is greater than the ulsion between b and c, and, therefore, N will be attracted to M by a e equal to the excess of the attractive over the repulsive force.

The moveable body is a conductor, and is electrified.—If the electricity he moveable body is different from that of the fixed body, there is ays attraction, but if they are of the same kind, there is at first re- ion and afterwards attraction. This anomaly may be thus explained:

Besides its charge of electricity, the moveable body contains neutra
This is decomposed by the induction of the positive fluid on M
consequently, the hemisphere *b* obtains an additional supply of p
electricity, while *a* becomes charged with negative electricity. Tl
thus attraction and repulsion, as in the foregoing case. The fo
repulsion is at first greater, because the quantity of positive fluid o
greater than that of negative fluid; but as the distance *a c* diminish
attractive force increases more rapidly than the repulsive force
finally exceeds it.

iii. *The moveable body is a bad conductor.*—If N is charged, rep
or attraction takes place, according as the electricity is of the sa
opposite kind to that of the fixed body. If it is in the natural
since a powerful and permanent source of electricity can more or le
compose the neutral fluid even in bad conductors, the body I
decompose the neutral fluid of N, and attraction will take place as
first case.

690. **Gold-leaf electroscope.**—The name *electroscope* is giv
instruments for detecting the presence, and determining the ki
electricity in any body. The original pith ball pendulum is an e
scope; but, though sometimes convenient, it is not sufficiently de
Many successive improvements have been made on it, and have re
in the form now generally used, which is due to Bennett.

Bennett's, or the gold-leaf electroscope.—This consists of a tul
glass shade (fig. 540), standing on a metallic foot, which thus com
cates with the ground. A metal rod terminating at its upper ext
in a knob, and holding at its lower end two narrow strips of gol
fits in the tubulure of the
the neck of which is coate
an insulating varnish. T
in the interior is dried by
lime, or by chloride of c
and on the insides of the
there are two strips of go
communicating with the gr

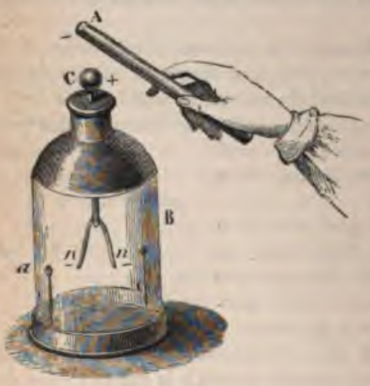


Fig. 540.

When the knob is t
with a body charged with
kind of electricity, the
diverge; usually, howev
apparatus is charged by in
thus :—

If an electrified body,
of sealing wax, for exam
brought near the knob,
decompose the natural electricity of the system, attracting to th
the electricity of the opposite kind and retaining it there, and r
the electricity of the same kind to the gold leaves, which conse
diverge. In this way the presence of an electrical charge is asc
but not its quality.

To ascertain the *kind* of electricity the following method is pursued :— while the instrument is under the influence of the body A, which we l suppose has a negative charge, the knob be touched by the finger, negative electricity decomposed by induction passes off into the und, and the previously divergent leaves will collapse : there only nains positive electricity, retained in the knob by induction from A. now the finger be first removed, and then the electrified body, the sitive electricity previously retained by A will spread over the system, l cause the leaves to diverge. If now, while the system is charged h positive electricity, a positively electrified body, as, for example, an cited glass rod, be approached, the leaves will diverge more widely; the electricity of the same kind will be repelled to the extremities. If, the contrary, an excited shellac rod be presented, the leaves will tend collapse, the electricity, with which they are charged, being attracted the opposite electricity. Hence we may ascertain the kind of electri-, either by imparting to the electroscope electricity from the body ler examination, and then bringing near it a rod charged with positive negative electricity; or the electroscope may be charged with a known d of electricity, and the electrified body in question brought near the ctroscope.

t has been proposed to use the electroscope as an *electrometer* or asurer of electricity, by measuring the angle of divergence of the ves ; it is said that for small angles the quantity of electricity is pro-tional to the sine of half the angle of deflection. This is done by cing behind them a graduated scale. There are, however, many ections to such a use, and the electroscope is rarely employed for this pose.

ELECTRICAL MACHINES.

91. **Electrophorus.**—It will now be convenient to describe the ious electrical machines, or apparatus, for generating and collecting ge supplies of statical electricity. One of the most simple and inex-nsive of these is the *electrophorus*, which was invented by Volta. Its ration, like that of all other electric machines, depends on the action nduction, of which it forms an excellent illustration. It consists of a e of resin, B (fig. 542), say about 12 inches diameter, and an inch k, which is placed on a metallic surface, or very frequently fits in a oden mould lined with tinfoil, which is called the *form*. Besides there is a metal disc, A (fig. 542), of a diameter somewhat less than of the cake, and provided with an insulating glass handle. The le of working this apparatus is as follows : All the parts of the appa-s having been well warmed, the cake, which is placed in the form, or s on a metallic surface, is briskly flapped with silk or flannel, or, er, a catskin, by which it becomes charged with negative electricity. cover is then placed on the cake. Owing, however, to the minute osities of the surface of the resin, the cover only comes in contact with w points, and, from the non-conductivity of the resin, the negative

electricity of the cake does not pass off to the cover. On the contrary, it acts by induction on the neutral electricity of the cover, and decomposes

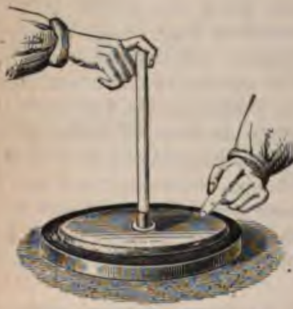


Fig. 541.

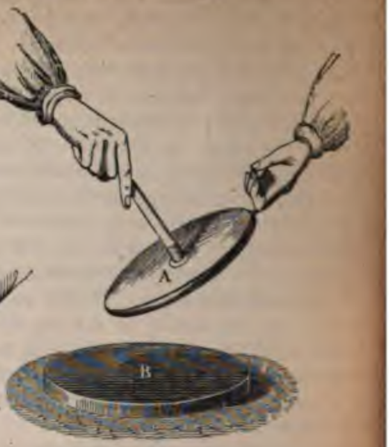


Fig. 542.

it, attracting the positive electricity to the under surface, and repelling the negative electricity to the upper. If the upper surface be now touched with the finger, the negative electricity, because repelled and free, passes off, and the cover remains charged with positive electricity, held, however, by the negative electricity of the cake; the two electricities do not unite, in consequence of the non-conductivity of the cake (fig. 541). If now the cover be raised by its insulating handle, the charge diffuses itself over the surface, and, if a conductor be brought near it, a small spark passes.

The metallic form on which the cake rests plays an important part in the action of the electrophorus, as it increases the quantity of electricity, and makes it more permanent. For the negative electricity of the upper surface of the resin, acting inductively on the neutral electricity of the lower, decomposes it, retaining on the under surface the positive electricity, while the negative electricity passes off into the ground. The positive electricity thus developed on the under surface reacts on the negative electricity of the upper surface, binding it, and causing it to penetrate into the badly conducting mass, on the surface of which fresh quantities of electricity can be excited, far beyond the limits possible without the action of the form. It is for this reason that the electrophorus, once charged, retains its state for a considerable time, and sparks can be taken from it even after a long interval. If the form be insulated, the charge obtained is far less than if it is on a conducting support. For the negative electricity developed by induction on the lower surface being now unable to escape, the condensing action referred to cannot take place, and only a feeble charge can be given to the resin. The retention

electricity is greatly promoted by keeping the cake in the form, and
cing the cover upon it, by which the access of air is hindered. Instead
a cake of resin, a disc of gutta percha, or vulcanised cloth, or vulcan-
, may be substituted; and, of course, if glass, or any material which
comes positively electrified by friction, be used, the cover acquires a
gative charge.

'The electrophorus is a good instance of the conversion of work
o electro-potential energy (58). When the cover is lifted from the
cited cake, work must be expended in order to overcome the
raction of the electricity in the cake, for the opposite electricity deve-
ped by induction on the cover; and the equivalent of this work appears
the form of the electricity thus detached. Thus, when a Leyden jar is
arged either by the machine or by the electrophorus, the energy of the
arge is a transformation of the work of the operator.'—TAIT.

692. **Plate electrical machine.**—The first electrical machine was

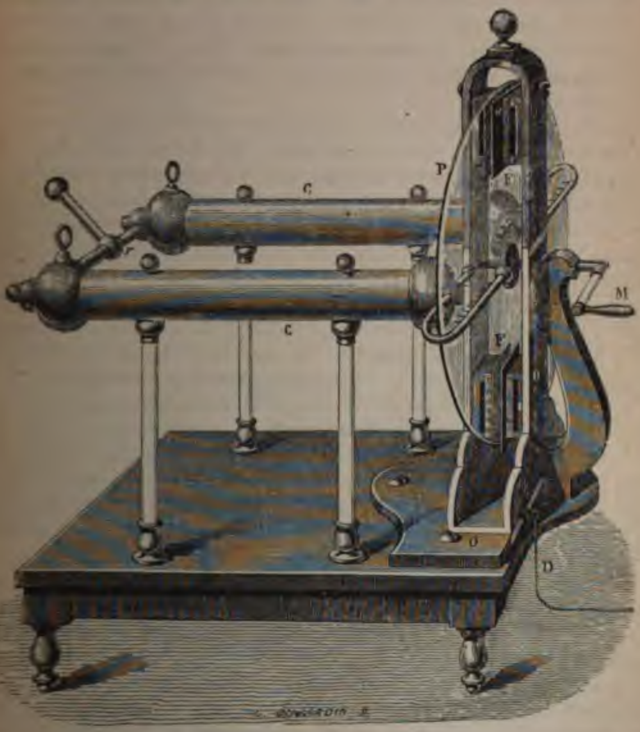


Fig. 543.

nted by Otto von Guericke, the inventor also of the air pump. It
sisted of a sphere of sulphur which was turned on an axis by means

of the hand, while the other, pressing against it, served as a
Resin was afterwards substituted for the sulphur, which,
Hawksbee replaced by a glass cylinder. In all these cases t
served as rubber; and Winckler, in 1740, first introduced cu
horsehair, covered with silk, as rubbers. At the same time B
lected electricity, disengaged by friction, on an insulated cylind
plate. Lastly, Ramsden, in 1760, replaced the glass cylind
circular glass plate, which was rubbed by cushions. The form w
machine has now is but a modification of Ramsden's original ma

Between two wooden supports (fig. 543) a circular glass pla
suspended by an axis passing through the centre, and which is
by means of a glass handle, M. The plate revolves between tw
cushions or *rubbers*, F, of leather or of silk, one set above the
one below, which, by means of screws, can be pressed as tightly
the glass as may be desired. The plate also passes between tw
rods shaped like a horse-shoe, and provided with a series of poin
sides opposite the glass: these rods are fixed to larger metallic cy
C, which are called the prime *conductors*. The latter are insul
being supported on glass feet, and are connected with each oth
smaller rod, *r*.

The action of the machine is founded on the excitation of el
by friction, and on the action of induction. By friction with the
the glass becomes positively and the rubbers negatively electrif
now the rubbers were insulated, they would receive a certain ch
negative electricity which it would be impossible to exceed,
tendency of the opposed electricities to reunite would be equal
power of the friction to decompose the neutral fluid. But the
communicate with the ground by means of a chain, and, conseque
fast as the negative electricity is generated, its tension is redu
zero by contact with the ground. The positive electricity of th
acts then by induction on the conductor, attracting the negative
city. This negative electricity collects in the points opposite
glass. Here its tension or tendency to discharge becomes so hig
passes across the intervening space of air, and neutralises the
electricity on the glass. The conductors thus lose their negativ
tricity, and remain charged with positive electricity. The plate
ingly gives up nothing to the prime conductors; in fact, it only al
from them their negative electricity.

If the hand be brought near the conductor when charged,
follows, which is renewed as the machine is turned. In this c
positive electricity decomposes the neutral fluid of the body, att
its negative electricity, and combining with it when the two have
cient tension. Thus, with each spark, the conductor reverts
neutral state, but becomes again electrified as the plate is turned.

693. **Precautions in reference to the machine.**—The glass, o
the plate is made, must be as little hygroscopic as possible.
ebonite has been frequently substituted for glass; it has the adv
of being neither hygroscopic nor fragile, and of readily becoming

›y friction. The plate is usually from $\frac{1}{12}$ to $\frac{1}{5}$ of an inch in thickness, from 20 to 30 inches in diameter, though these dimensions are not :quently exceeded.

ıe rubbers require great care, both in their construction and in their :rvation. They are commonly made of leather, stuffed with horse- Before use they are coated either with powdered *aurum musivum* huret of tin), or graphite, or amalgam. The action of these sub- :es is not very clearly understood. Some consider that it merely ists in promoting friction. Others, again, believe that a chemical n is produced, and assign, in support of this view, the peculiar smell ed near the rubbers when the machine is worked. Amalgams, per- , promote most powerfully the disengagement of electricity. *Kien- r's amalgam* is the best of them. It is prepared as follows : one of zinc and one part of tin are melted together, and removed from re and two parts of mercury stirred in. The mass is transferred wooden box containing some chalk, and then well shaken. The gam, before it is quite cold, is powdered in an iron mortar, and pre- d in a stoppered glass vessel. For use, a little cacao butter or lard read over the cushion, some of the powdered amalgam sprinkled it, and the surface smoothed by a ball of flattened leather.

order to avoid a loss of electricity, two quadrant-shaped pieces of silk are fixed to the rubbers, so as to cover the plate on both sides, t the upper part from *a* to F, and the other in the corresponding of the lower rubbers. These flaps are not represented in the figure. ıw oiled silk is the best, and there must be perfect contact between late and the cloth.

ımsden's machine, as represented in fig. 543, only gives positive ricity. But it may be arranged so as to give negative electricity by ng it on a table with insulating supports. By means of a chain, the uctor is connected with the ground, and the machine worked as e. The positive electricity passes off by the chain into the ground, the negative electricity remains in the supports and in the insulated . On bringing the finger near the uprights, a sharper spark than the ary one is obtained.

ł. **Maximum of tension.**—It is impossible to exceed a certain of electrical tension with the machine, whatever precautions are l, or however rapidly the plate is turned. This limit is attained the loss of electricity equals its production. The loss depends on causes: i. The loss by the atmosphere, and the moisture it con- ; this is proportional to the tension. ii. The loss by the supports. he recombination of the electricities of the rubbers and the glass.

e first two causes have been already mentioned. With reference to tter, it must be noticed that the electrical tension increases with the ity of the rotation, until it reaches a point at which it overcomes the ınce presented by the non-conductivity of the glass. At this point, tion of the two electricities separated on the rubbers and on the recombines, and the tension remains constant. It is, therefore, ıtely independent of the rapidity of rotation.

last

695. **Quadrant electrometer.**—The electric tension is measured the *quadrant* or *Henley's electrometer*, which is attached to the conduct

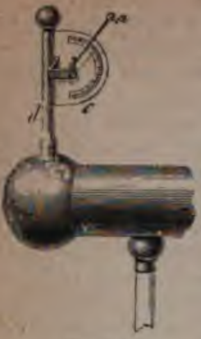


Fig. 544.

This is a small electric pendulum, consisting of wooden rod, *d*, to which is attached an ivory cardboard scale, *c* (fig. 544). In the centre of th is a small whalebone index, moveable on an ax and terminating in a pith ball, *a*. Being attach to the conductor, the index diverges as the machi is charged, ceasing to rise when the limit attained. When the rotation is discontinued t index falls rapidly if the air is moist, but in d air it only falls slowly, showing, therefore, that th loss of electricity in the latter case is less than the former.

696. **Cylinder electrical machine.**—The co struction of the cylinder machines, as ordinari used in England, is due to Nairne. They are w adapted for obtaining either kind of electricity. In Nairne's machi (fig. 545) the cylinder is rubbed by only one cushion, C, which is ma of leather stuffed with horsehair, and is screwed to an insulated conducto A. On the opposite side of the cylinder there is a similar insulated co

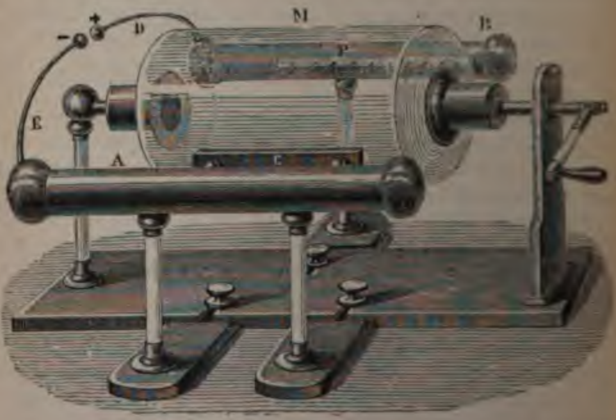


Fig. 545.

ductor, B, provided with a series of points on the sides next the gl To the lower part of the cushion C is attached a piece of oiled s which extends over the cylinder to just above the points. This is not presented in the figure. When the cylinder is turned, A becomes charg with negative and B with positive electricity by the loss of its nega from the points P. The two opposite electricities will now unite by succession of sparks across D and E. If use be made of the electrici either the rubber or the prime conductor must be connected with t

. In the former case positive electricity is obtained, in the latter 'e.

Armstrong's hydro-electric machine.—In this machine elec- is produced by the disengagement of aqueous vapour through orifices. The discovery of the machine was occasioned by an ıt. A workman having accidentally held one hand in a jet of which was issuing from an orifice in a steam boiler at high pres- 'hile his other hand grasped the safety valve, was astonished at ıncing a smart shock. Sir W. Armstrong (then Mr. Armstrong, vcastle), whose attention was drawn to this phenomenon, ascer- that the vapour was charged with positive electricity, and by re- ; the experiment with an insulated locomotive, found that the was negatively charged. Armstrong believed that the electricity ıe to a sudden expansion of the vapour ; Faraday, who afterwards ıed the question, ascertained its true cause, which will be best tood after describing a machine which Armstrong devised for re- ing the phenomenon.

ɔnsists of a boiler of wrought-iron plate (fig. 546), with a central

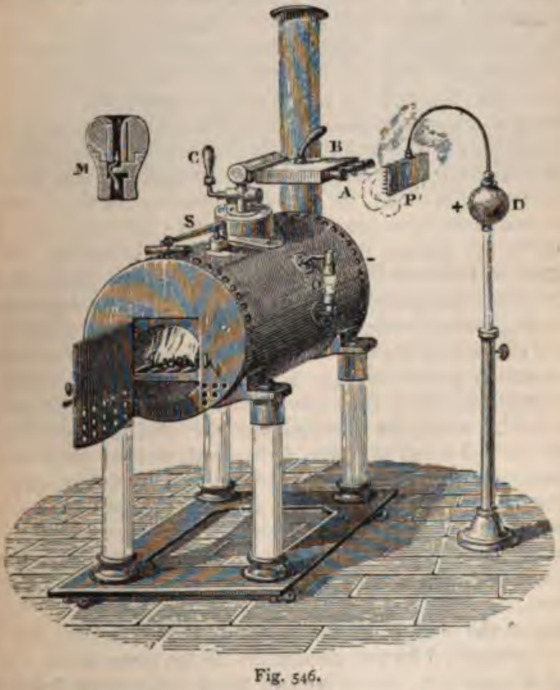


Fig. 546.

d insulated on four legs. It is about 5 feet long by 2 feet in ɪr, and is provided at the side with a gauge, O, to show the height of the water in the boiler. C is the stopcock, which is opened when the vapour has sufficient tension. Above this is the box, B, in which are the tubes through which the vapour is disengaged. On these are fitted jets of a peculiar construction, which will be understood from the section of one of them, M, represented on a larger scale. They are lined with hard wood in a manner represented by the diagram. The box B contains cold water. Thus, the vapour, before escaping, undergoes partial condensation, and becomes charged with vesicles of water; a necessary condition, for Faraday found that no electricity is produced when the vapour is perfectly dry.

The development of electricity in the machine was at first attributed to the condensation of the vapour, but Faraday found that it is solely due to the friction of the globules of water against the jet. For if the little cylinders which line the jets are changed, the kind of electricity is changed; and if ivory is substituted, little or no electricity is produced. The same effect is produced if any fatty matter is introduced into the boiler. In this case the linings are of no use. It is only in case the water is pure that electricity is disengaged, and the addition of acid or saline solutions, even in minute quantity, prevents any disengagement of electricity. If turpentine is added to the boiler, the effect is reversed—the vapour becomes negatively, and the boiler positively, electrified.

With a current of moist air Faraday obtained effects similar to those of this apparatus, but with dry air no effect is produced.

698. **Holtz's electrical machine.**—Before the end of last century electrical machines were known in this country in which the electricity was not developed by friction, but by the continuous inductive action of a body already electrified, as the electrophorus; within the last few years such machines have been reinvented and come into use. The form represented in fig. 547 was invented by M. Holtz, of Berlin.

It consists of two circular plates of thin glass at a distance of 3 mm. from each other; the larger one, A A, which is 2 feet in diameter, is fixed by means of 4 wooden rollers, resting on glass axes and glass feet. The diameter of the second plate, B B, is 2 inches less; it turns on a horizontal glass axis, which passes through a hole in the centre of the large fixed plate. In the plate A, on the same diameter, are two large apertures, or windows, F F′. Along the lower edge of the window F, on the posterior face of the plate, a band of paper, *p*, is glued, and on the anterior face a sort of tongue of thin cardboard, *n*, joined to *p* by a thin strip of paper, and projecting into the window. At the upper edge of the window, F′, there are corresponding parts, *p′* and *n′*. The papers *p* and *p′* constitute the *armatures*. The two plates, the armatures, and their tongues are carefully covered with shellac varnish, but more especially the edges of the tongues.

In front of the plate B, at the height of the armatures, are two brass *combs*, *o o′*, supported by two conductors of the same metal, *c c′*. In the front end of these conductors are two pretty large brass knobs, through which pass two brass rods terminated by smaller knobs, *r r′*, and provided with wooden handles, K K′. These rods, besides moving with gentle riction in the knobs, can also be turned so as to be more or less ap-roached and inclined towards each other. The plate is turned by means

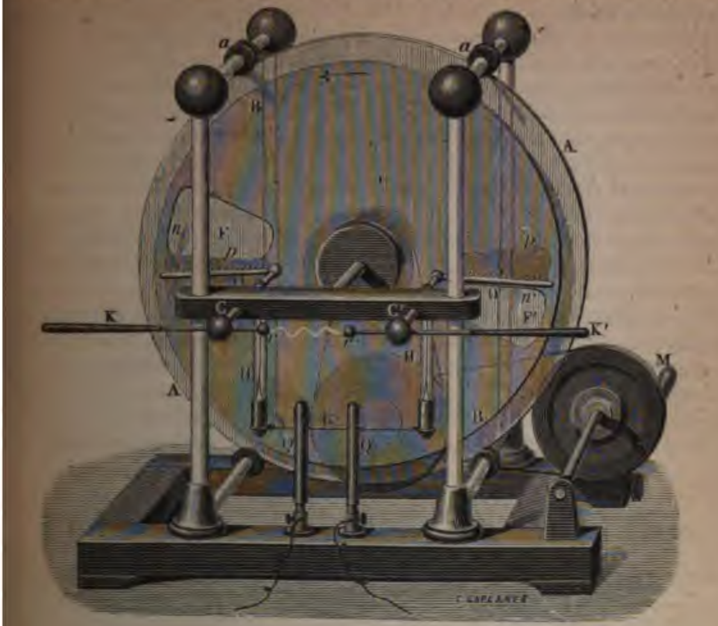


Fig. 547.

f a winch, M, and a series of pulleys which transmit its motion to the xis; the velocity which it thus receives is 12 to 15 turns in a second, nd the rotation should take place in the direction indicated by the arrow—hat is, towards the points of the cardboard tongues *n n'*.

To work the machine the armatures *p p'* must be first *primed*; that is, ne of the armatures is positively and the other negatively electrified. his is effected by means of a sheet of ebonite, which is excited by triking it with flannel, or, better, with catskin; the two knobs *r r'* aving been connected, the electrified ebonite is brought near one of hem, *p*, for instance, and the plate is turned. The ebonite is charged ith negative electricity, which, acting inductively on the armature *p*, ecomposes its neutral fluid. and the negative electricity repelled is ischarged by the tongue on to the moveable plate, the armature re-aining charged with positive electricity. After half a turn the negative ectricity of the plate coming in front of the window F' acts in the same ay on the armature *p'*, charging it with negative electricity by taking om it a corresponding quantity of positive electricity by the tongue *n'* fter a few turns the two armatures being thus electrified, one positively nd the other negatively, the inducing plate of ebonite is removed, and the knobs r r' separated, as represented in the figure. On continuin turn the plate uninterrupted, a torrent of sparks strikes across from knob to the other.

These details being known, the following is the explanation of action, as given by Riess. When a conductor is under the influence of electrified body, it becomes charged with opposite electricities on its opposite surfaces (684). This is also the case with non-conductors, w the difference, that the separation of the two electricities, which is inst taneous in the first case, takes place slowly in the second. But if betw the source of electricity and a good conductor a bad conductor, such a plate of glass, be interposed, the inductive action is modified. Suppos the source of electricity to be positive, if its action be prolonged, the go and the bad conductors are negatively electrified on the side turned towa the source, and positively on the opposite side.

If the inductive action is of short duration the influence is weak, a the electricity with which the glass plate is charged on its posterior f is negative electricity imparted by the good conductor, especially if it provided with points. The plate B is thus electrified negatively on t two faces; a phenomenon which Riess calls *double influence.*

That being granted, let fig. 548 represent a horizontal projection of t

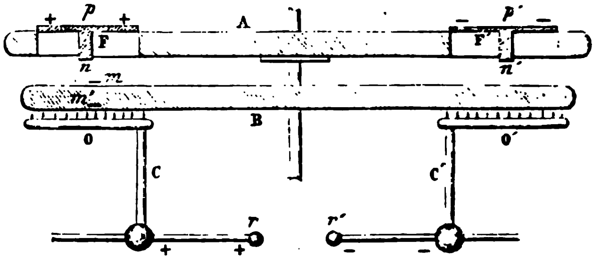


Fig. 548.

details of fig. 547, the letters having in both cases the same meaning. T two armatures p and p', having been electrified, as we have above seen, positively and the other negatively, when two opposite elements, m and of the plate B, pass in front of the window F, from what has been s above, the elements m and m', in the presence of the positive armatur both become negatively electrified; at the same time the conductor which has imparted its negative electricity to the face m of the plat remains positively electrified. Then, the rotation continuing, the elem m and m' both come in front of the window F F' negatively charged. Th the element m', adding its influence to that of the negative armatur withdraws from the conductor C'r' its positive electricity, and charg with negative electricity. The element m, acting inductively on the ar ture p', withdraws positive fluid from it by induction, and thus tend keep it in the negative state. The two elements m and m' revert to ositive state, and passing in front of the window F, the same series of henomena is reproduced.

In Holtz's machine electricity is used in three forms, which double inluence can develope. The *free* electricity of conductors is used in experinents. The electricity induced upon the external face of the moveable isc, and the electricity *communicated* to the inner face, are removed by he disc, and serve to keep up the charge of the armatures. The line of he combs divides this disc in two halves, which are every minute elecrified in opposite directions. Each of them is of the same kind as the onductor or armature towards which it is moving, and of opposite sign o the comb towards which the rotation carries it. The nature of the lectricity is observed from the shape of the brush which escapes from it; he brushes are long and verging on the positive comb; short and like uminous points on the negative comb.

With plates of equal dimensions Holtz's machine is far more powerful han the ordinary electrical machine (692). The power is still further ncreased by suspending to the conductors C C′ two *condensers*, H H′ 704), which consist of two glass tubes coated with tin foil, inside and ut, to within a fifth of their height. Each of them is closed by a cork, hrough which passes a rod, communicating at one end with the inner oating, and suspended to one of the conductors by a crook at the other nd. The two external coatings are connected by a conductor, G. They re, in fact, only two small Leyden jars (709), one of them, H, becoming harged with positive electricity on the inside, and negative on the outde; the other, H′, with negative electricity on the inside, and positive on he outside. Becoming charged by the intervention of the machine, and eing discharged at the same rate by the knobs *r r′*, they strengthen the park, which may attain a length of 6 or 7 inches.

The current of the machine is utilised by placing in part of the frame wo brass uprights, Q Q′, with binding screws in which are copper wires; hen, by means of the handles K K′, the rods which support the knobs *r r′*, re inclined, so that they are in contact with the uprights. The current eing then directed by the wires, a battery of six jars can be charged in few minutes, water can be decomposed, a galvanometer deflected, and eissler's tubes worked as with the voltaic pile.

The electrical current of a Holtz's machine has been shown by Poggenorff to be independent of the resistance of the circuit, and by Kohlrausch o be proportional to the velocity of rotation. A plate 46 inches in iameter revolving 5 times in three seconds produced a constant current apable of decomposing water at the rate of 3½ millionths of a milliramme per second, or equal to that of a Grove's cell in a circuit of 5,000 B A units (861).

699. **Bertsch's machine.**—This is a simpler, though at the same time ss powerful, apparatus than Holtz's machine, with which it has otherise much similarity.

It consists of an ebonite plate, P P′, about 18 inches in diameter, and ounted on a glass axis (fig. 549). The inducing plate E, represented eparately at the top of the figure as E′, is also of ebonite, and is placed in a groove at the base of the machine, near the plate P P′, but not i contact with it. The inducing plate E having been electrified, wi

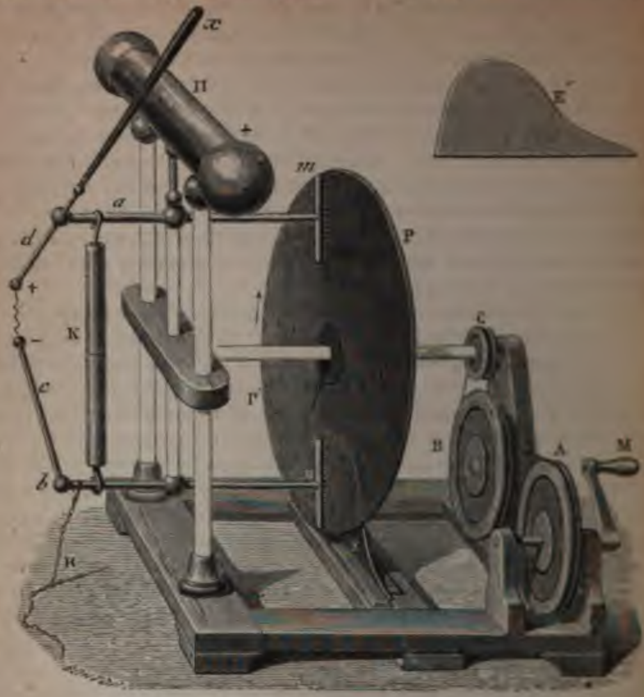


Fig. 549.

negative electricity suppose, acts through the plate P on a comb *n*, wit drawing from it positive electricity, which passes to the plate and rep negative to the conductor *b*. The plate, continuing to turn, arrives charg with positive electricity in front of the second comb *m*. Hence it wi draws from the comb, and from the conductor *a*, negative electricit which restores it to the neutral state, and the conductor *a* remains po tively charged. As the rotation of the plate is continued the conducto *a* and *b* continue to become charged with opposite electricities, and if th knobs are at a distance of 3 to 4 inches, an uninterrupted succession o sparks passes between them.

The intensity of the sparks increases when the conductor *b* is connect with the ground by means of a chain R. It is further increased by int posing a condenser, K, between the conductors *a* and *b*. This consists two glass tubes cemented together at the bottoms. At each end is curved wire connected with the internal lining, which is of tinfoil. single sheet of tinfoil coats the outside, so that they are no more than tw small Leyden jars connected by their outside coatings. They becom rged with contrary electricities from the conductors *a* and *b*, and being charged at the same time as them, increase the spark.

The power is increased by placing close to the sector A a second ilar one, electrified in the same manner. As the inducing power inases, the tension also increases. With a machine thus arranged, a ss plate $\frac{1}{8}$ to $\frac{1}{6}$ of an inch may be perforated, and a strong battery idly charged. The inducing power of the sectors quickly decreases, l they must be excited afresh.

3oth Holtz's and Bertsch's machines are very much affected by the isture of the air; but M. Ruhmkorff has found that, spreading on the le a few drops of petroleum, the vapours which condense on the chine protect it against the moisture of the atmosphere.

These machines are small in compass, and not very expensive, and uire less force for working them than frictional machines. When the

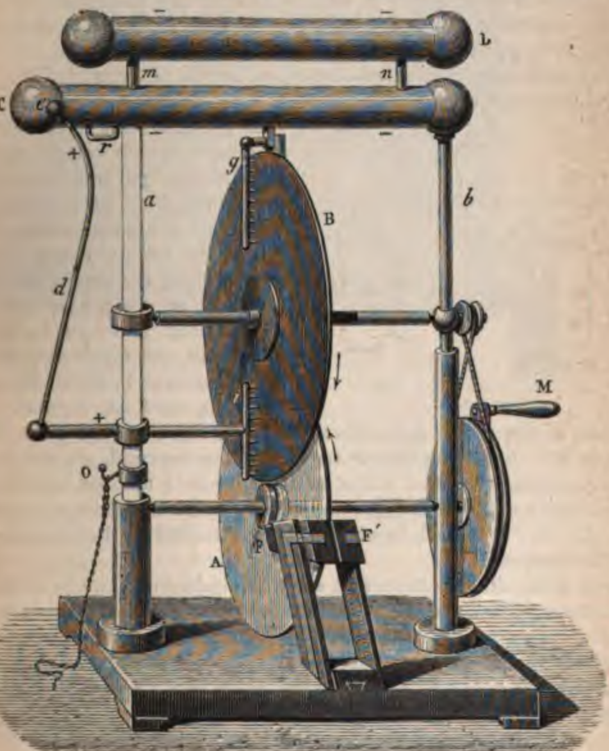


Fig. 550.

natures are electrified, more resistance is experienced in turning the te than if they are not electrified; in the former case part of the mechanical force exerted by the arm of the operator is transformed into electricity.

700. **Carré's dielectrical machine.**—This is a combination of the old form of machine with that of Holtz.

It consists of two plates turning in opposite directions (fig. 550), one, A, of glass and the other of ebonite. They overlap each other to about $\frac{2}{3}$ to $\frac{3}{4}$ of their radii. The lower one is slowly turned by means of a handle, M, while the upper one is rapidly rotated by an endless cord, which passes from the large over the small wheel.

The plate A, after having been electrified positively between two rubbers F F′, acts inductively through the plate B on a comb *i*, withdrawing from it negative electricity, which then passes to the plate B, the conductor *d e* remaining positively electrified; but as the plate B turns very quickly, the negative electricity, as it collects on its surface, acts inductively on a second comb, *g*, which it charges with negative electricity, reverting itself to the neutral state, while the two conductors C and D, which are connected with the comb *g*, become charged with negative electricity.

These conductors, connected as they are by two ties, *m* and *n*, rest on two columns, the one, *a*, of glass, and the other, *b*, of ebonite. A chain in connexion with the ground is suspended from a hook, O, which can be raised at pleasure, and put in connexion with the comb *i*. The rubbers F F′, moreover, are in connexion with the ground by means of two bands of tin foil along the supports.

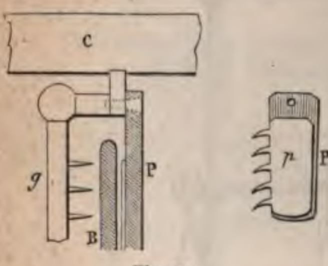


Fig. 551.

Lastly, at *p* (fig. 551) is a sector of varnished paper cut in the form of a comb, and fastened to an insulating segment, P, of the same shape, which is used as support. From the teeth of the sector *p* positive electricity flows on the plate B as it moves, and by induction this sector *p* yields to the comb *g* a surcharge of negative electricity. The rod *d* and the knob *e* may be withdrawn at will from the conductor C (fig. 550), so that sparks of different lengths may be taken. At *r* is a hook to which can be attached the Leyden jars which are to be charged.

Owing to the direct action, and when the inducing plate is as the maximum charge, Carré's machine is not very much affected by moisture, and it yields a larger supply of electricity. With plates whose dimensions are respectively 38 and 49 centimètres, it gives sparks of 15 to 18 centimètres, and more when a condenser is added, as in Holtz's and Bertsch's machines.

EXPERIMENTS WITH THE ELECTRICAL MACHINE.

701. **Spark.**—One of the most curious phenomena observed with the electrical machine is the spark drawn from the conductor when a finger is presented to it. The positive electricity of the conductor, acting in-

ctively on the neutral fluid of the body, decomposes it, repelling the itive and attracting the negative fluid. When the tension of the op- ed electricities is sufficiently great to overcome the resistance of the

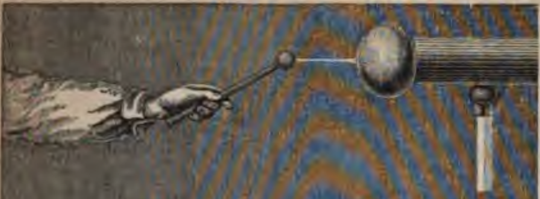


Fig. 552.

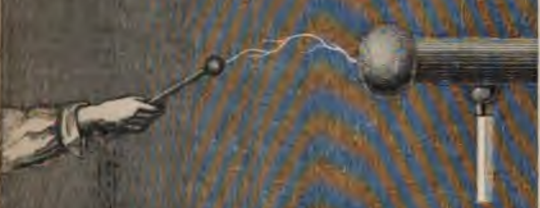


Fig. 553.

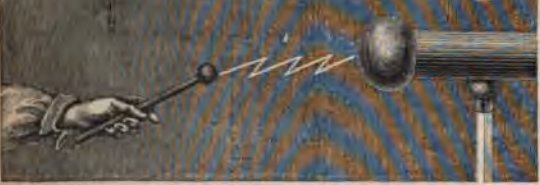


Fig. 554.

, they recombine with a smart crack and a spark. The spark is tantaneous, and is accompanied by a sharp prickly sensation, more ecially with a powerful machine. Its shape varies. When it strikes a short distance, it is rectilinear, as seen in fig. 552. Beyond two or ee inches in length, the spark become irregular, and has the form of inuous curve with branches (fig. 553). If the discharge is very verful, the spark takes a zig-zag shape (fig. 554). These two latter earances are seen in the lightning discharge.

spark may be taken from the human body by the aid of the *insulating ol*, which is simply a low stool with stout glass legs. The person stand- on this stool touches the prime conductor, and as the human body is onductor, the electrical fluid is distributed over its surface as over an inary insulated metallic conductor. The hair diverges in consequenc epulsion, a peculiar sensation is felt on the face, and if another person, nding on the ground, presents his hand to any part of the body, a smart ck with a pricking sensation is produced.

person standing on an insulated stool may be positively electrified by ng struck with a catskin. If the person holding the catskin stands on insulated stool, the striker becomes positively, and the person struck atively, electrified.

702. **Electrical chimes.**—The *electrical chimes* is a piece of apparat consisting of three bells suspended to a horizontal metal rod (fig. 555 Two of them, A and B, are in metallic connection with the c ductor; the middle bell hangs by a silk thread, and is thus insulat from the conductor, but is connected with the ground by means a chain. Between the bells are small copper balls suspended by s threads. When the machine is worked, the bells A and B, being positive electrified, attract the copper ba and after contact repel them. Be now positively electrified, they a in turn attracted by the midd bell, C, which is charged with neg tive electricity by induction fro A to B. After contact they a again repelled, and this process repeated as long as the machin is in action.

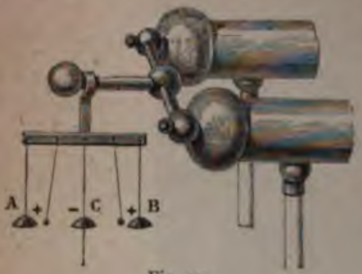


Fig. 555.

Fig. 556 represents an apparat originally devised by Volta for th purpose of illustrating what he sup posed to be the motion of hail between two clouds oppositely electrifie It consists of a tubulated glass shade, with a metal base, on which a

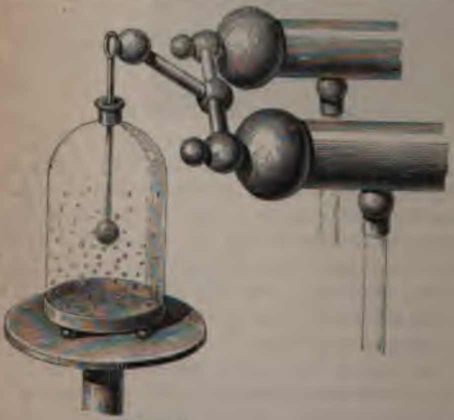


Fig. 556.

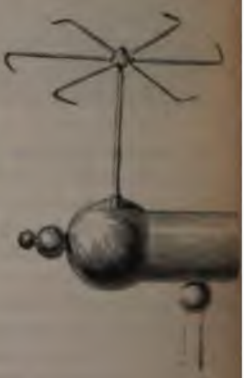


Fig. 557.

some pith balls. The tubulure has a metal cap, through which passe brass rod, provided with a metallic disc or sphere at the lower end, a at the upper with a knob, which touches the prime conductor.

When the machine is worked, the sphere, becoming positively elect fied, attracts the light pith balls, which are then immediately repelled, a having lost their charge of positive electricity, are again attracted, ag repelled, and so on, as long as the machine continues to be worked. A amusing modification of this experiment is frequently made by plac ween the two plates small pith figures, somewhat loaded at the base. ıen the machine is worked, the figures execute a regular dance.

03. **Electrical whirl or vane.**—The electrical *whirl* or *vane* consists 5 or 6 wires, terminating in points, all bent in the same direction, and ed in a central cap, which rotates on a pivot (fig. 557). When the paratus is placed on the conductor, and the machine worked, the irl begins to revolve in a direction opposite that of the points. This tion is not analogous to that of the hydraulic tourniquet (204). It is t caused by a flow of material fluid, but is owing to a repulsion between electricity of the points and that which they impart to the adjacent by conduction. The electricity being accumulated on the points in a h state of tension, passes into the air, and imparting thus a charge of ctricity, repels this electricity, while it is itself repelled. That this is case is evident from the fact that, on approaching the hand to the irl while in motion, a slight draught is felt, due to the movement of the ctrified air, while in vacuo the apparatus does not act at all. This ught or wind is known as the electrical *aura.*

When the electricity thus escapes by a point, the electrified air is elled so strongly as not only to be perceptible to the hand, but also to ender a current strong enough to blow out a candle. Fig. 558 shows

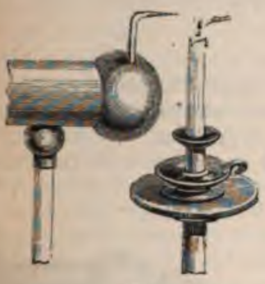


Fig. 558.

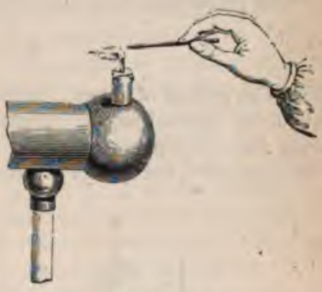


Fig. 559.

s experiment. The same effect is produced by placing a taper on the ductor, and bringing near it a pointed wire held in the hand (fig. 559). e current arises in this case from the contrary fluid, which escapes the point under the influence of the machine.

The *electrical orrery* and the *electrical inclined plane* are analogous to se pieces of apparatus.

CHAPTER IV.

CONDENSATION OF ELECTRICITY.

04. **Condensers. Theory of condensers.**—A *condenser* is an appa-s for condensing a large quantity of electricity on a comparatively ll surface. The form may vary considerably, but in all cases consists

essentially of two insulated conductors, separated by a non-conductor, the working depends on the action of induction.

Epinus's condenser consists of two circular brass plates, A and

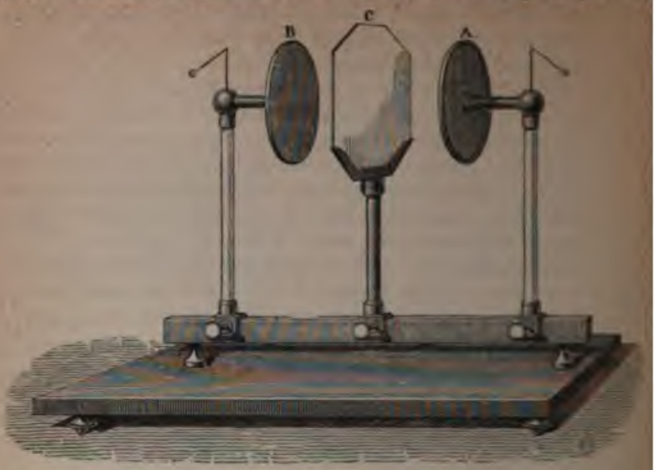


Fig. 560.

(fig. 560), with a sheet of glass, C, between them. The plates, each provid with a pith ball pendulum, are mounted on insulated glass legs, and be moved along a support, and fixed in any position. When electricit to be accumulated, the plates are placed in contact with the glass,

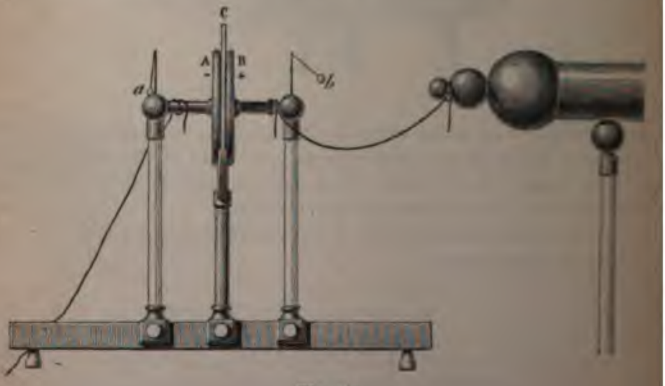


Fig. 561.

then one of them, B for instance, is connected with the electrical machi and the other placed in connection with the ground, as shown in fig.

In explaining the action of the condenser, it will be convenient in ease to call that side of the metal plate nearest the glass the *anterior*, and the other the *posterior* side. And first let A be at such a distance from B as to be out of the sphere of its action. The plate B, which is then connected with the conductor of the electrical machine, takes its maximum charge, which is distributed equally on its two faces, and the pendulum diverges widely. If the connection with the machine be interrupted, nothing would be changed; but if the plate A be slowly approached, its neutral fluid being decomposed by the influence of B, the negative is accumulated on its anterior face, *n* (fig. 562), and the positive passes into the ground. But as the negative electricity of the plate A reacts in its turn on the positive of the plate B, the latter fluid ceases to be equally distributed on both faces, and is accumulated on its anterior face, *m*. The posterior face, *p*, having thus lost a portion of its electricity, its tension has diminished, and is no longer equal to that of the machine, and the pendulum, *b*, diverges less widely. Hence B can receive a fresh quantity from the machine, which, acting as just described, decomposes by induction a second quantity of neutral fluid on the plate A. There is then a new accumulation of negative fluid on the face *n*, and consequently of positive fluid on *m*. But each time that the machine gives off electricity to the plate, only a part of this passes to the face *m*, the other remaining on the face *p*; the tension here, therefore, continues to increase until it equals that of the machine. From this moment equilibrium is established, and a limit to the charge attained which cannot be exceeded. The quantity of electricity accumulated now on the two faces *m* and *n* is very considerable, and yet the pendulum diverges just as much as it did when A was absent, and no more; in fact, the tension at *p* is just what it was then—namely, that of the machine.

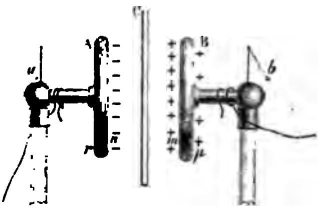


Fig. 562.

When the condenser is charged—that is, when the opposite electricities are accumulated on the anterior faces—connection with the ground is broken by raising the wires. The plate A is charged with negative electricity, but simply on its anterior face (fig. 562), the other side being neutral. The plate B, on the contrary, is electrified on both sides, but unequally; the accumulation is only on its anterior face, while on the posterior, *p*, the tension is simply equal to that of the machine at the moment the connections are interrupted. In fact, the pendulum *b* diverges and *a* remains vertical. But if the two plates are removed, the two pendulums diverge (fig. 560), which is owing to the circumstance that, as the plates no longer act on each other, the positive fluid is equally distributed on the two faces of the plate B, and the negative on those of the plate A.

705. **Slow discharge and instantaneous discharge.**—While the plates A and B are in contact with the glass (fig. 561), and the connections interrupted, the condenser may be discharged—that is, restored to

the neutral state, in two ways; either by a slow or by an instantaneous discharge. To discharge it slowly, the plate B—that is, the one containing an excess of electricity—is touched with the finger; a spark passes, all the electricity on p passes into the ground, the pendulum b falls, but a diverges. For B, having lost part of its electricity, only retains on the face m that held by the inductive influence of the negative on A. But the quantity thus retained at B is less than that on A; this has free electricity, which makes the pendulum a diverge, and if it now be touched, a spark passes, the pendulum a sinks while b rises, and so on by continuing to touch alternately the two plates. The discharge only takes place slowly; in very dry air it may require several hours. If the plate A were touched first, no electricity would be removed, for all it has is retained by that of the plate B. To remove the total quantity of electricity by the method of alternate contacts, an infinite number of such contacts would theoretically be required, as will be seen from the following calculation:

Let the total quantity of positive electricity on B be taken $=1$; by induction it retains on A a quantity less than its own of negative electricity; let this quantity be called m; m being a fraction in all cases less than unity, but which varies with the distance of the plates and the nature of the dielectric. Now the m of negative electricity on A, reacting in turn on the positive on B, retains there $m \times m = m^2$ of positive electricity, and therefore the free electricity on B, that which makes the pendulum b diverge, is $1 - m^2$, and if B be touched this quantity is removed. The m of negative on A now retains, on B, m^2 of positive; this binds in turn m times its own quantity—that is, m^3 of negative on A—and the free negative electricity which now makes the pendulum a diverge is represented by $m - m^3 = m(1 - m^2)$. If A be now touched, this quantity is removed, the pendulum a sinks and b rises; for B has now an excess of free electricity, which it is readily seen is represented by $m^2(1 - m^2)$. By pursuing this reasoning, it will be seen that the following expresses the quantities removed and left after each successive contact:—

Positive			Negative
	1	m	
$1 - m^2$;	m^2	m^3;	$m(1 - m^2)$
$(1 - m^2)m^2$;	m^4	m^5;	$m^3(1 - m^2)$
$(1 - m^2)m^4$;	m^6	m^7;	$m^5(1 - m^2)$
$(1 - m^2)m^{n-2}$;	m^n	m^{n+1};	$m^{n-1}(1 - m^2)$

An instantaneous discharge may be effected by means of the *discharging rod* (fig. 563). This consists of two bent brass wires, terminating on knobs, and joined by a hinge. When provided with glass handles, as in fig. 563, it forms a *glass discharging rod.* In using this apparatus one of the knobs is pressed against one plate of the condenser, and the other knob brought near the other. At a certain distance a spark strikes from the plate to the knob, caused by the sudden recomposition of the two opposite electricities.

When the condenser is discharged by the discharger no sensation is

, even though the latter be held in the hand; of the two con- electric fluid always chooses the better, and hence the dis- fected through the metal, and not through the body. But if, and is in contact with one plate, the other touches the second, ;e takes place through the breast and arms, and a considerable ; and the larger the surface of the con- the greater the electric tension, the t is the shock.

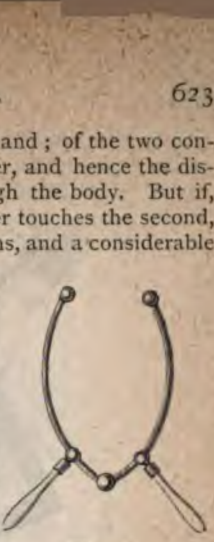


Fig. 563.

ulation of the condensing force.— sing force is the relation between the ;e, which the collecting plate can take r the influence of the second plate, ich it would take if alone; in other the relation of the total quantity of n the collecting plate to that which e; for it is assumed that the quantity ricity on the collecting plate is the same :h it would take if it were alone.

ate the condensing force, let us, as before, express the total positive electricity which the collecting plate B can take, the influence of the condensing plate, by 1, then *m* is the tity of negative electricity on the second plate. But, as we een, the quantity of free electricity on B is $1-m^2$. Hence

: fraction which expresses the condensing force.

: of *m* is determined experimentally by means of the proof the torsion balance. Thus, if *m* were 0·99, the quantity of hich could be accumulated on the collecting plate B, under e of A, would be 50 times as much as the quantity it could one; while, if *m* were 0·75, the quantity would be 2·28 times

lt of the charge of condensers.—The quantity of electricity e accumulated on each plate is, *cæteris paribus*, proportional on of the electricity on the conductor, and to the surface of it decreases as the insulating plate is thicker, and it differs ecific inductive capacity of the substance. Two causes limit y of electricity which can be accumulated. First, that the ion of the collecting plates gradually increases, and ultimately of the machine, which cannot, therefore, impart any free The second cause is the imperfect resistance which the late offers to the recombination of the two opposite electricities; e force which impels the two fluids to recombine exceeds the ffered by the insulating plate, it is perforated, and the contrary

minating pane. Franklin's plate.—This is a simple form nser, and is more suitable for giving strong shocks and sparks. of a glass plate fixed in a wooden frame (fig. 564); on each glass pieces of tin foil are fastened opposite each other, leaving the neutral state, in two ways; either by a slow or by an instant discharge. To discharge it slowly, the plate B—that is, the one cont an excess of electricity—is touched with the finger; a spark pas the electricity on *p* passes into the ground, the pendulum *b* falls diverges. For B, having lost part of its electricity, only retains face *m* that held by the inductive influence of the negative on A. quantity thus retained at B is less than that on A; this has free elect which makes the pendulum *a* diverge, and if it now be touched, a passes, the pendulum *a* sinks while *b* rises, and so on by continu touch alternately the two plates. The discharge only takes place sl in very dry air it may require several hours. If the plate A touched first, no electricity would be removed, for all it has is retair that of the plate B. To remove the total quantity of electricity method of alternate contacts, an infinite number of such contacts theoretically be required, as will be seen from the following ca tion:

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Positive		Negative	
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$(1 - m^2)m^2$;	m^4	m^5;	$m^3(1 - m^2)$
$(1 - m^2)m^4$;	m^6	m^7;	$m^5(1 - m^2)$
$(1 - m^2)m^{n\ 2}$;	m^n	$m^n + {}^1$;	$m^n - {}^1(1 - m^2)$

An instantaneous discharge may be effected by means of the *disc ing rod* (fig. 563). This consists of two bent brass wires, terminati knobs, and joined by a hinge. When provided with glass handl in fig. 563, it forms a *glass discharging rod.* In using this apparatu of the knobs is pressed against one plate of the condenser, an other knob brought near the other. At a certain distance a spark s from the plate to the knob, caused by the sudden recomposition two opposite electricities.

When the condenser is discharged by the discharger no sensati experienced, even though the latter be held in the hand; of the two conductors, the electric fluid always chooses the better, and hence the discharge is effected through the metal, and not through the body. But if, while one hand is in contact with one plate, the other touches the second, the discharge takes place through the breast and arms, and a considerable shock is felt; and the larger the surface of the condenser, and the greater the electric tension, the more violent is the shock.

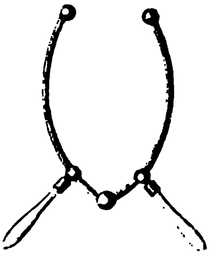


Fig. 563.

706. **Calculation of the condensing force.**—The condensing force is the relation between the whole charge, which the collecting plate can take while under the influence of the second plate, to that which it would take if alone; in other words, it is the relation of the total quantity of electricity on the collecting plate to that which remaïns free; for it is assumed that the quantity of free electricity on the collecting plate is the same as that which it would take if it were alone.

To calculate the condensing force, let us, as before, express the total quantity of positive electricity which the collecting plate B can take, while under the influence of the condensing plate, by 1, then m is the whole quantity of negative electricity on the second plate. But, as we have just seen, the quantity of free electricity on B is $1-m^2$. Hence $\frac{1}{1-m^2}$ is the fraction which expresses the condensing force.

The value of m is determined experimentally by means of the proof plane and the torsion balance. Thus, if m were 0·99, the quantity of electricity which could be accumulated on the collecting plate B, under the influence of A, would be 50 times as much as the quantity it could receive if alone; while, if m were 0·75, the quantity would be 2·28 times as great.

707. **Limit of the charge of condensers.**—The quantity of electricity which can be accumulated on each plate is, *cæteris paribus*, proportional to the tension of the electricity on the conductor, and to the surface of the plates: it decreases as the insulating plate is thicker, and it differs with the specific inductive capacity of the substance. Two causes limit the quantity of electricity which can be accumulated. First, that the electric tension of the collecting plates gradually increases, and ultimately equals that of the machine, which cannot, therefore, impart any free electricity. The second cause is the imperfect resistance which the insulating plate offers to the recombination of the two opposite electricities: for when the force which impels the two fluids to recombine exceeds the resistance offered by the insulating plate, it is perforated, and the contrary fluids unite.

708. **Fulminating pane. Franklin's plate.**—This is a simple form of the condenser, and is more suitable for giving strong shocks and sparks. It consists of a glass plate fixed in a wooden frame (fig. 564): on each side of the glass pieces of tin foil are fastened opposite each other, leaving

then the external coating touched, either with the hand or with a metallic conductor. A slight spark is seen at each discharge.

Fig. 567 represents a very pretty experiment for illustrating the slow discharge. The rod terminates in a small bell, *d*, and the outside coating is connected with an upright metallic support, on which is a similar bell, *e*. Between the two bells a light copper ball is suspended by a silk thread. The jar is then charged in the usual manner and placed on the support *m*. The internal coating contains a quantity of free electricity; the pendulum is attracted and immediately repelled, striking against the second bell, to which it imparts its free electricity. Being now neutralised, it is again attracted by the first bell, and so on for some time, especially if the air be dry, and the jar pretty large.

710. **Leyden jar with moveable coatings.**—This apparatus (fig. 568) is used to demonstrate that in the Leyden jar, the opposite electricities are not distributed on the coatings merely, but reside principally on the opposite sides of the glass. It consists of a somewhat conical glass vessel, B, with moveable coatings of zinc or tin, C and D. These separate pieces placed one in the other, as shown in figure A, form a complete Leyden jar. After having charged the jar, it is placed on a cake of resin; the internal coating is first removed by the hand, or better a glass rod, and then the glass vessel. The coatings are found to contain very little electricity, and if they are placed on the table they are restored to the neutral state. Nevertheless, when the jar is put together again, as represented in the figure at A, a shock may be taken from it almost as strong as if the coatings had not been removed. It is therefore concluded that the coatings merely play the part of conductors, distributing the electricity over the surface of the glass, which thus becomes polarised, and retains this state even when placed on the table, owing to its imperfect conductivity.

The experiment may be conveniently made by forming a Leyden jar, of which the inside and outside coatings are of mercury, charging it; then, having mixed the two coatings, the apparatus is put together again, upon which a discharge may be once more taken.

711. **Lichtenberg's figures.**—This experiment well illustrates the opposite electrical conditions of the two coatings of a Leyden jar. Holding a jar charged with positive electricity by the hand, a series of lines are drawn with the knob on a cake of resin or vulcanite; then having placed the jar

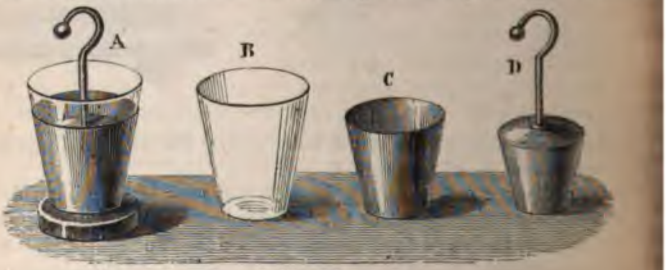


Fig. 568.

on an insulator, it is held by the knob, and another series traced by means of the outer coating. If now an intimate mixture of red lead and flour of sulphur be projected on the cake, the sulphur will attach itself to the positive lines, and the red lead to the negative lines; the reason being that in mixing the powders the sulphur has become negatively electrified, and the red lead positively. The sulphur will arrange itself in tufts with numerous diverging branches, while the red lead will take the form of small circular spots, indicating a difference in the distribution of the two electricities on the surface of the resin.

712. **Penetration of the charge. Residual charge.**—Not only do the electricities adhere to the two surfaces of the insulating medium which separates them, but they penetrate to a certain extent into the interior, as is shown by the following experiments: A condenser is formed of a plate of shellac, and moveable metallic plates. It is then charged, retained in that state for some time, and afterwards discharged. On removing the metallic coatings and examining both surfaces of the insulator, they show no signs of electricity. After some time, however, each face exhibits the presence of some electricity of the same kind as that of the plate with which it was in contact while the apparatus was charged. This can be explained by assuming that the electricity had slowly penetrated from the exterior to the interior during the first phase of the experiment, and had eturned to the surface during the second.

A phenomenon frequently observed in Leyden jars is of the same nature. Vhen a jar has been discharged and allowed to stand a short time, it exibits a second charge, which is called the *electric residue*. The jar may e again discharged, and a second residue will be left, feebler than the rst, and so on, for three or four times. Indeed with a delicate electroscope long succession of such residues may be demonstrated. Time is required r the penetration of the electricities into the mass; and hence the residue greater the longer the jar has remained charged. The magnitude of the sidue further depends on the intensity of the charge, and also on the egree of contact of the metallic plates with the insulator. It varies with e nature of the substance, but there is no residue with either liquids or seous insulators. Faraday found that with paraffine the residue was eatest, then with shellac, while with glass and sulphur it was least of all. ohlrausch has found that the residue is nearly proportional to the thickss of the insulator.

713. **Electric batteries.**—The charge which a Leyden jar can take pends on the extent of the coated surface, and for small thicknesses is ersely proportional to the thickness of the insulator. Hence, the larger d thinner the jar the more powerful the charge. But very large jars are pensive, and liable to break; and when too thin, the accumulated ctricities are apt to discharge themselves through the glass, especially t is not quite homogeneous. Leyden jars have usually from $\frac{1}{2}$ to 3 are feet of coated surface. For more powerful charges electric batteries used.

An *electric battery* consists of a series of Leyden jars, whose internal and ernal coatings are respectively connected with each other (fig. 569).

They are usually placed in a wooden box lined on the bottom with ti
This lining is connected with two metallic handles in the sides of the
The internal coatings are connected with each other by metallic rods,
the battery is charged by placing the internal coatings in connection
the prime conductor, while the external coatings are connected wit
ground by means of a chain fixed to the handles. A quadrant electro

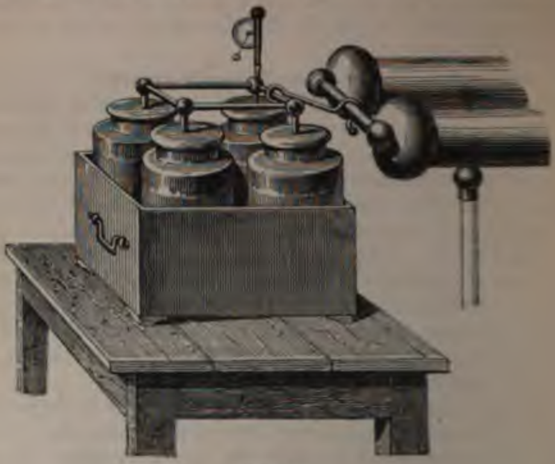


Fig. 569.

fixed to the jar serves to indicate the charge of the battery. Al
there is a large quantity of electricity accumulated in the apparat
divergence is not great, for it is simply due to the free electricity
internal coating. The number of jars is usually four, six, or nine.
larger and more numerous they are, the longer is the time requi
charge the battery, but the effects are so much the more powerful.

When a battery is to be discharged, the coatings are connect
means of the discharging rod, the outside coating being touched
Great care is required, for with large batteries serious accident
occur, resulting even in death.

714. **The universal discharger.** — This is an almost indispe
apparatus in experiments with the electric battery. On a wooden
(fig. 570) are two glass legs, each provided with universal joints, in
moveable brass rods are fitted. Between these legs is a small ivory
on which is placed the object under experiment. The two metal
being directed towards the objects, one of them is connected wi
external coating of the battery, and the moment communication is
between the other and the internal coating by means of the gla
charging rod, a violent shock passes through the object on the tabl

715. **Charging by cascade.**—A series of Leyden jars are place
separately on insulating supports. The knob of the first is in conn
with the prime conductor of the machine, and its outer coating jo

e knob of the second, the outer coating of the second to the knob of the ird, and so on; the outer coating of the last communicating with the

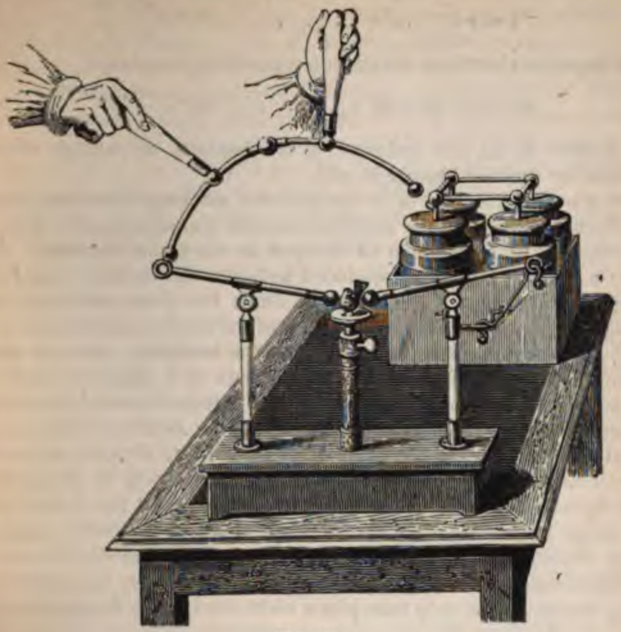


Fig. 570.

round. The inner coating of the first receives a charge of positive elec- icity from the machine, and the corresponding positive electricity set ee by induction on its outer coating, instead of passing to the ground, ives a positive charge to the inner coating of the second, which, acting like manner, developes a charge in the third jar, and so on, to the last, here the positive electricity developed by induction on the outer coating sses to the ground. The jars may be discharged either singly, by con- ecting the inner and outer coatings of each jar, or simultaneously by nnecting the inner coating of the first with the outer of the last. In is way the quantity of electricity necessary to charge one jar is avail- le for charging a series of jars.

For from the preceding explanation it is clear, that with a series of milar Leyden jars charged by cascade, if we call the charge of positive ectricity which the inside of the first jar receives 1, it will develope by duction on the outside a quantity $m (m < 1)$ of negative electricity, and e same quantity m of positive electricity which will pass into the side of the second jar; this in turn will develope $m \times m = m^2$ of negative ectricity on the outside of that jar, and the same quantity m^2 of positive ectricity will pass into the inside of the third jar, and so forth. Thus it will be seen that the quantities of positive electricity developed in a s of *n* similar jars by the unit charge of positive electricity will be

$$1 + m + m^2 + m^3 + \quad . \quad . \quad . \quad . \quad m^{n-1} = \frac{1 - m^n}{1 - m}$$

and of negative electricity on the corresponding outsides of

$$m + m^2 + m^3 + m^4 + \quad . \quad . \quad . \quad . \quad m^n = \frac{m(1 - m^n)}{1 - m}$$

Thus, if there be six jars and $m = 0{\cdot}9$, the quantity of positive electri developed by the unit charge is 4·69.

If the external coatings of a charged and uncharged jar are place connection, and if the inner coatings are now connected, after separa them they are both found to be charged in the same manner. In process a current has been produced between the outside coatings one between the inner ones, to which Dove has given the name *cha current*, and which has all the properties of the ordinary discharge curr

716. **Measurement of the charge of a battery. Lane's elect meter.**—When the outer and inner coatings of a charged Leyden are gradually brought near each other, at a certain distance a spontane discharge ensues. This distance is called the *striking distance.* I inversely proportional to the pressure of the air and directly proportio to the electric density of that point of the inner coating at which the charge takes place. As the density of any point of the inner coati other things remaining the same, is proportional to the entire charge, striking distance is proportional to the quantity of electricity in a The measurement of the charge of a battery, however, by means of striking distance, can only take place when the charge disappears.

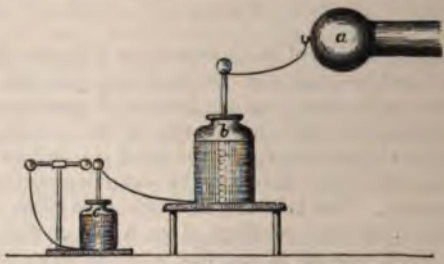


Fig. 571.

By means of Lane's electrometer, which depends on an applicati of this principle, the charge of a jar or battery may be measured. Th apparatus, *c* (fig. 571), consists of an ordinary Leyden jar, near whi there is a vertical metallic support. At the upper end is a brass r with a knob at one end, which can be placed in metallic connection wi the outside of the jar : the rod being moveable, the knob can be kept a measured distance from the knob of the inner coating. Fig. 571 repr sents the operation of measuring the charge of a jar by means of this a paratus. The jar *b*, whose charge is to be measured, is placed on an ated stool with its outer coating in metallic connection with the inner ating of Lane's jar *c*, the outer coating of which is in connection with ground, or still better with a system of gas or water pipes; *a* is the nductor of the machine. When the machine is worked, positive eleccity passes into the jar *b*; a proportionate quantity of positive electriy is repelled from its outer coating, passes into the inner coating of the ctrometer, and there produces a charge. When this has reached a rtain limit, it discharges itself between the two knobs, and so often as ch a discharge takes place, the same quantity of positive electricity will ve passed from the machine into the battery; and hence its charge is portional to the number of discharges of the electrometer.

Harris's unit jar (fig. 572) is an application of the same principle, and very convenient for measuring quantities of electricity. It consists of a all Leyden phial 4 inches in length, and $\frac{3}{4}$ of an inch in diameter ated to about an inch from the d, so as to expose about 6 inches coated surface. It is fixed hori- ntally on a long insulator, and charging rod connected at P th the conductor of the machine, ile the outer coating is connected th the jar or battery by the rod When the accumulation of ctricity in the interior has reached ertain height depending on the distance of the two balls *m* and *n*, a charge ensues, and marks a certain quantity of electricity received as a arge by the battery, in terms of the small jar.

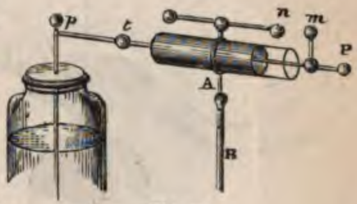


Fig. 572.

717. **Laws of electric charge.**—Harris, by means of experiments with unit jar suitably modified, and Riess, by analogous arrangements, have ind, by independent researches, that for small distances the striking tance is directly proportional to the quantity of electricity, and inversely portional to the extent of coated surface; in other words, it is propornal to the electric density. Thus, taking the surface of one jar as ity, if a battery of six Leyden jars charged by 100 turns of the machine s a striking distance of 9 millimeters, a battery of four similar jars arged by 120 turns will have the striking distance of 16·2 millimeters. r

$$\frac{100}{6} : 9 = \frac{120}{4} : x$$
$$x = 16{\cdot}2.$$

e charge also depends on the nature of the glass, or other dielectric, of ich the jar is made; and further, is stated by Wheatstone to be ersely proportional to the square of the thickness of the dielectric. ss has also found that when a battery or jar is discharged in the king distance, a charge still remains, for when the coatings are brought rer a similar discharge may be taken, and so on. The amount of this idual charge when the discharge takes place at the greatest striking tance is *always in the same proportion to the entire charge.* In Riess's experiments, 0·846 or $\frac{11}{13}$ of the total charge disappear, and onl remain.

718. **Volta's condensing electroscope.**—The condensing electrosc invented by Volta is a modification of the ordinary gold leaf electrosc (690). The rod to which the gold leaves are affixed terminates in disc instead of in a knob, and there is another disc of the same size pr vided with an insulating glass handle. The discs are covered with a lay of insulating shellac varnish (fig. 573).

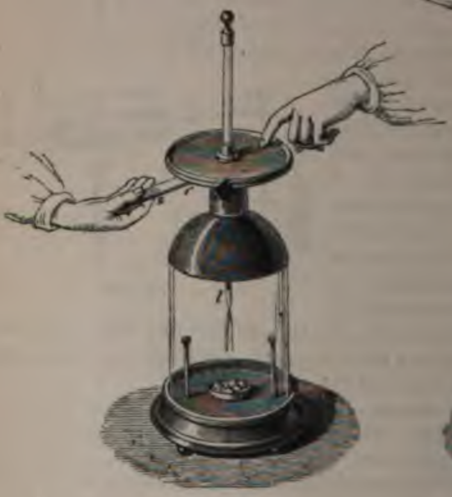


Fig. 573.

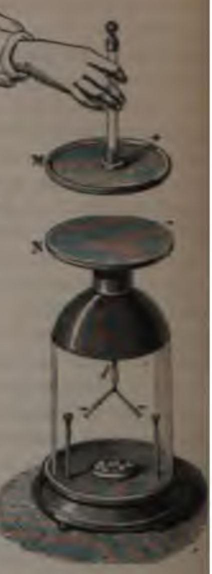


Fig. 574.

To render very small quantities of electricity perceptible by this ap ratus, one of the plates, which thus becomes the *collecting plate*, is touc with the body under examination. The other plate, the *condensing pl* is connected with the ground by touching it with the finger. The el tricity of the body, being diffused over the collecting plate, acts ind tively through the varnish on the neutral fluid of the other plate, attract the opposite electricity, but repelling that of like kind. The two elec cities thus become accumulated on the two plates just as in Epi condenser, but there is no divergence of the leaves, for the oppo electricities counteract each other. The finger is now removed, and t the source of electricity, and still there is no divergence ; but if the up plate be raised (fig. 574) the neutralisation ceases, and the electricity be free to move diffuses itself over the rod and the leaves, which t diverge widely. The delicacy of the apparatus is increased by adap to the foot of the apparatus two metallic rods, terminating in knobs,

obs being excited by induction from the gold leaves react upon

further degree of delicacy is attained by replacing the rods by nenberger's dry piles, one of which presents its positive and the negative pole. Instead of two gold leaves there is only one; the ce of electricity causes it to oscillate either to one side or to the id at the same time shows the kind of electricity.

homson's electrometer.—Sir William Thomson has devised a delicate form of electrometer, by which quantitative measure- the amount of electrical charge may be made. The principle of rument may be understood from the following description of a it constructed for lecture purposes by Messrs. Elliot.

t flat broad aluminium needle hangs by a very thin wire from the ating of a charged Leyden jar, the outer coating being in con- ommunication with the he whole apparatus is within a glass shade air kept dry by means of sulphuric acid; there fore, very little loss of y and the needle at a virtually constant

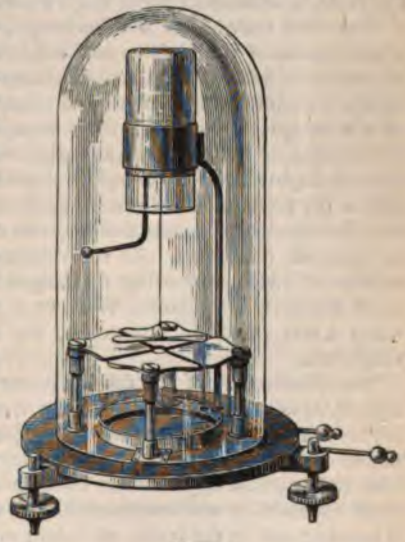


Fig. 575.

eedle is suspended over adrantal metal plates from each other and ground by resting on ands. The alternate s are in conducting ication with each other s of wires. If now all lrants are in the same condition, the needle rest when it is directly of the diametrical slits. two pairs of quadrants ged with opposite kinds city, as when, for instance, they are connected with the two poles ulated voltaic cell by means of the knobs, then each end of the ill be repelled by the pair of quadrants which are electrified like will be attracted by the other pair. It will thus be subject to n of a couple tending to set it obliquely to the slit.

er to render the slightest motion of the needle visible, a small ncave mirror with a radius of about a metre is fixed above it. of a petroleum lamp, not represented in the figure, strikes his and is reflected as a spot of light on a horizontal scale. Any of the needle either on one side or the other, is indicated by n of the spot of light on the scale.

THE ELECTRIC DISCHARGE.

720. **Effects of the electric discharge.**—The recombination
two electricities which constitutes the electrical discharge may be
continuous or sudden ; *continuous*, or of the nature of a current, as
the two conductors of a cylinder machine are joined by a chain or a
and *sudden*, as when the opposite electricities accumulate on the s
of two adjacent conductors, till their mutual attraction is strong e
to overcome the intervening resistances, whatever they may be. E
difference between a sudden and a continuous discharge is one of c
and not of kind, for there is no such thing as an absolute non-con
and the very best conductors, the metals, offer an appreciable resi
to the passage of electricity. Still, the difference at the two extre
the scale is sufficiently great to give rise to a wide range of phenon

Riess has shown that the discharge of a battery does not cons
simple union of the positive and negative electricity, but that it c
of a series of successive partial discharges. The direction of the dis
depends mainly on the length and nature of the circuit. By obser
of the image of the spark in a rotating mirror, and of the lu
phenomena at the positive and negative poles when the discharg
place in highly rarefied gases, as well as by the manner in which a r
affects the phenomena of discharge, Feddersen and Paalzow have
that the discharge consists of a series of oscillating currents alte
in opposite directions. As the resistance of the circuit increas
number of these alternating discharges decreases, but at the sam
their duration is greater. With very great resistance, as for in
when a wet thread is interposed, the alternating discharge bec
single one.

The phenomena of the discharge are usually divided into the
logical, *luminous*, *mechanical*, *magnetical*, and *chemical* effects.

721. **Physiological effects.**—The physiological effects are thos
duced on living beings, or on those recently deprived of life. In th
case they consist of a violent excitement which the electric fluid
on the sensibility and contractibility of the organic tissues through
it passes; and in the latter, of violent muscular convulsions which
ble a return to life.

The shock from the electrical machine has been already noticed
The shock taken from a charged Leyden jar by grasping the e
coating with one hand and touching the inner with the other, is
more violent, and has a peculiar character. With a small jar the
is felt in the elbow; with a jar of about a quart capacity it is felt
the chest, and with jars of still larger dimensions in the stomach.

A shock may be given to a large number of persons simultaneou
means of the Leyden jar. For this purpose they must form a ch
joining hands. If then the first touches the outside coating of a cl
jar, while the last at the same time touches the knob, all receive a
taneous shock, the intensity of which depends on the charge, and

number of persons receiving it. Those in the centre of the chain are found to receive a less violent shock than those near the extremities. The Abbé Nollet discharged a Leyden jar through an entire regiment of 1500 men, who all received a violent shock in the arms and shoulders.

With large Leyden jars and batteries the shock is sometimes very dangerous. Priestley killed rats with batteries of 7 square feet coated surface, and cats with a battery of about 4½ square yards coating.

722. **Luminous effects.**—The recomposition of two electricities of high tension is always accompanied by a disengagement of light, as is seen when sparks are taken from a machine, or when a Leyden jar is discharged. The better the conductors on which the electricities are accumulated, the more brilliant is the spark; its colour varies not only with the nature of the bodies, but also with the nature of the surrounding medium and with the pressure. The spark between two charcoal points is yellow, between two balls of silvered copper it is green, between knobs of wood or ivory it is crimson. In atmospheric air at the ordinary pressure the electric spark is white and brilliant; in rarefied air it is reddish; and in vacuo it is violet. In oxygen, as in air, the spark is white; in hydrogen it is reddish; and green in the vapour of mercury; in carbonic acid it is also green, while in nitrogen it is blue or purple, and accompanied by a peculiar sound. Generally speaking, the higher the tension the greater is the lustre of the spark. It is asserted by Fusinieri that in the electric spark there is always a transfer of material particles in a state of extreme tenuity, in which case the modifications in colour must be due to the transport of ponderable matter.

When the spark is viewed through a prism, the spectrum obtained is full of dark lines (527), the number and arrangement of which depend on the nature of the poles.

723. **Spark and brush discharge.**—The shapes which luminous electric phenomena assume may be classed under two heads—the *spark* and the *brush*. The brush forms when the electricity leaves the conductor in a continuous flow; the spark, when the discharge is discontinuous. The formation of one or the other of these depends on the nature of the conductor and on the nature of the conductor in its vicinity; and small alterations in the position of the surrounding conductors transform the one into the other.

The spark which at short distances appears straight, at longer distances has a zigzag-shape with diverging branches. Its length depends on the tension at the part of the conductor from which it is taken; and to obtain the longest sparks the electricity must be of as high tension as possible, but not so high as to discharge spontaneously. With long sparks the luminosity is different in different parts of the spark.

The brush derives its name from the radiating divergent arrangement of the light, and presents the appearance of a luminous cone, whose apex touches the conductor. Its size and colour differ with the nature and form of the conductor; it is accompanied by a peculiar hissing noise, very different from the sharp crack of the spark. Its luminosity is far less than that of the spark, for while the latter can easily be seen by daylight, the former is only visible in a darkened room. Th discharge may be obtained by placing on the conductor a wire file at the end, or, with a powerful machine, by placing a small bulle conductor. The brush from a negative conductor is less than positive conductor; the cause of this difference has not bee factorily made out, but may originate in the fact, which Farac observed, that negative electricity discharges into the air at what lower tension than positive electricity; so that a negatively knob sooner attains that tension at which spontaneous discharg place than does a positively charged one, and therefore dischar electricity at smaller intervals and in less quantities.

When electricity, in virtue of its high tension, issues from a co no other conductor being near, the discharge takes place withou and at the places at which it appears there is a pale blue lun called the *electrical glow*, or on points, a star-like centre of ligh seen in the dark by placing a point on the conductor of the mach

724. **Electric egg.**—The influence pressure of the air on the electric light studied by means of the *electric egg* consists of an ellipsoidal glass vessel (f with metal caps at each end. The lo is provided with a stopcock, so that it screwed into an air pump, and also into metallic foot. The upper metallic roc up and down in a leather stuffing b lower one is fixed to the cap. A vacuun been made, the stopcock is turned, vessel screwed into its foot; the upper then connected with a powerful electr chine, and the lower one with the grou working the machine, the globe becom with a feeble violet light continuous fr end to the other, and resulting from composition of the positive fluid of th cap with the negative of the lower. I be gradually allowed to enter by open stopcock, the tension of the electricity i with the resistance, and the light now white and brilliant, and is only seen ordinary intermittent spark.

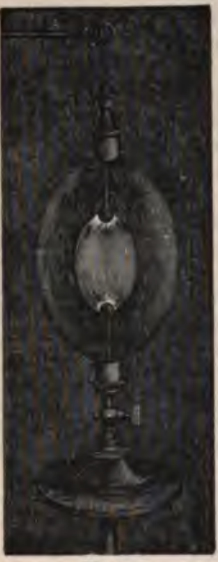


Fig 576.

Some beautiful effects of the electric light are obtained by n Geissler's tubes, which will be noticed under Dynamical Electric

725. **Luminous tube, square, and bottle.**—The *lumino* (fig. 577) is a glass tube about a yard long, round which are arr a spiral form a series of lozenge-shaped pieces of tin foil, between v very short intervals. There is a brass cap with hooks at each which the spiral terminates. If one end be presented to a ma action, while the other is held in the hand, sparks appear simult

each interval, and produce a brilliant luminous appearance, especially the dark.

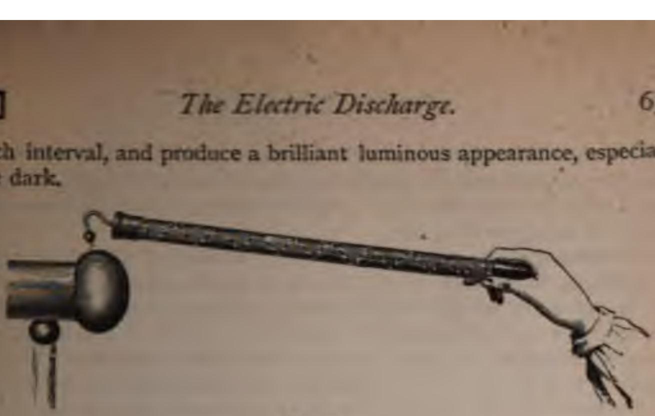


Fig. 577

The *luminous pane* (fig. 578) is constructed on the same principle, and nsists of a square of ordinary glass, on which is fastened a narrow strip tin foil folded parallel to itself for a great number of times. Spaces e cut out of this strip so as to represent any figure, a portico for example.

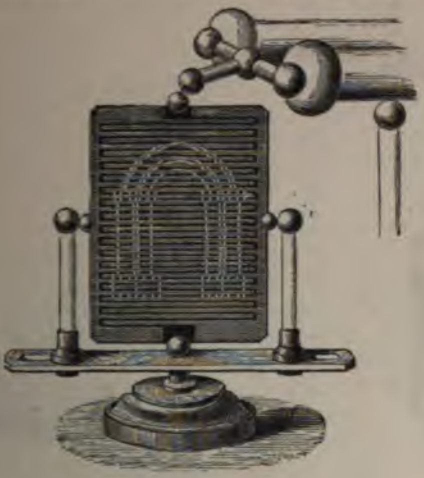


Fig. 578.

e pane being fixed between two insulating supports, the upper tremity of the strip is connected with the electrical machine, and the wer part with the ground. When the machine is in operation, a spark pears at each interval, and reproduces in luminous flashes the object presented on the glass.

The *luminous jar* (fig. 579) is a Leyden jar, whose outer coating nsists of a layer of varnish strewed over with metallic powder. A ip of tin fitted on the bottom is connected with the ground by means a chain ; a second band at the upper part of the coating has a ojecting part, and the rod of the bottle is curved so that the knob is about $\frac{3}{4}$ of an inch distant from the projection. This bottle is suspen from the machine, and as rapidly as this is worked, large and brilli sparks pass between the knob and the outer coating, illuminating outside of the apparatus.

726. **Calorific effects.**—Besides being luminous, the electric sp is a source of intense heat. When it passes through inflamm liquids, as ether or alcohol, it inflames them. An arrangement effecting this is represented in figure 580. It is a small glass through the bottom of which passes a metal rod, terminating in a k and fixed to a metal foot. A quantity of liquid sufficient to cover knob is placed in the vessel. The outer coating of the jar having b connected with the foot by means of a chain, the spark which pas when the two knobs are brought near each other inflames the liq With ether the experiment succeeds very well, but alcohol requires to first warmed.

Coal gas may also be ignited by means of the electric spark. A pers

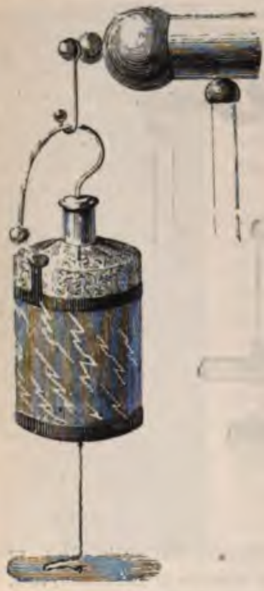


Fig. 579.

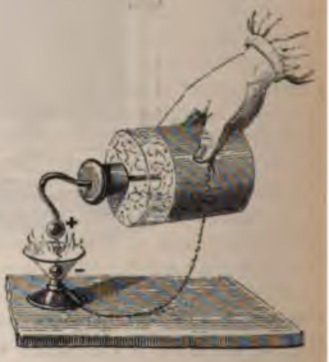


Fig. 580.

standing on an insulated stool places one hand on the conductor o machine which is then worked, while he presents the other to the jet of issuing from a metallic burner. The spark which passes ignites the g When a battery is discharged through an iron or steel wire it becom heated, and even made incandescent or melted, if the discharge is v powerful.

The laws of this heating effect have been investigated independently y Harris and by Riess by means of the *electric thermometer.* This essentially an air thermometer, across the bulb of which is a fine atinum wire. When a discharge is passed through the wire it becomes eated, expands the air in the bulb, and this expansion is indicated in ie motion of the liquid along the graduated stem of the thermometer. this way it has been found that the increase in temperature in the wire proportional to the electric density multiplied by the quantity of ectricity; and since the electric density is equal to the quantity of ectricity—usually measured by the number of discharges of the unit r (716),—divided by the surface, the heating effect is proportional to the quare of the number of discharges divided by the surface; that is, $h = \frac{q^2}{s}$.

Riess has also found that *with the same charge, but with wires of ifferent dimensions, the rise of temperature is inversely as the fourth ower of the diameter.* Thus, compared with a given wire as unity, the *ise of temperature* in a wire of double or treble the diameter would be $\frac{1}{16}$ r $\frac{1}{81}$ as small; but as the masses of these wires are four and nine times s great, *the heat produced* would be respectively $\frac{1}{4}$ and $\frac{1}{9}$ as great as in a ire of unit thickness.

When an electric discharge is sent through gunpowder placed on the ble of a Henley's discharger, it is not ignited, but is projected in all irections. But if a wet string be interposed in the circuit a spark asses which ignites the powder. This arises from the retardation hich electricity experiences in traversing a semi-conductor, such as a et string: for the heating effect is proportional to the duration of the ischarge.

When a charge is passed through sugar, heavy spar, fluorspar, and ther substances, they afterwards become phosphorescent in the dark. ggs, fruit, etc., may be made luminous in the dark in this way.

When a battery is discharged through a gold leaf, pressed between two lass plates or between two silk ribbons, the gold is volatilised in a violet owder which is finely divided gold. In this way the electric portraits re obtained.

Siemens has shown that when a jar is charged and discharged several mes in succession it becomes heated. Hence there must be movements the molecules of the glass as Faraday has supposed.

727. **Magnetic effects.**—By the discharge of a large Leyden jar or attery, a steel wire may be magnetised if it is laid at right angles to a onducting wire through which the discharge is effected, either in contact ith the wire or at some distance. And even with less powerful discharges, steel bar or needle may be magnetised by placing it inside a tube on hich is coiled a fine insulated copper wire. On passing the discharge rough this wire the steel becomes magnetised.

To effect a deflection of the magnetic needle by the electric current roduced by frictional electricity is more difficult. It may be accomished by making use of a galvanometer consisting of 400 or 500 rns of fine silk-covered wire, which is further insulated by being coated with shellac varnish, and by separating the layers by mean oiled silk. When the prime conductor of a machine in action is c nected with one end of the galvanometer wire, and the other with ground, a deflection of the needle is produced.

728. **Mechanical effects.**—The mechanical effects are the viol lacerations, fractures, and sudden expansions which ensue when a pow ful discharge is passed through a badly-conducting substance. Glas

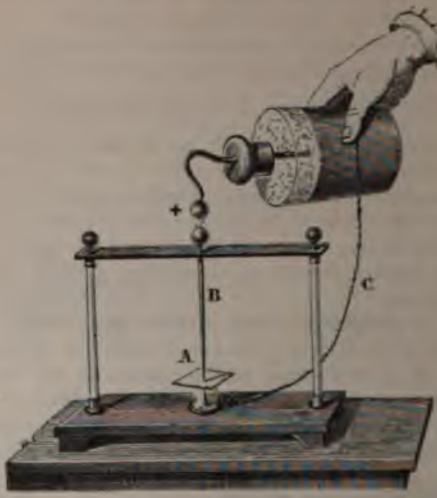


Fig. 581.

perforated, wood and stones are fractured, and gases and liquids are lently disturbed. The mechanical effects of the electric spark ma demonstrated by a variety of experiments.

Figure 581 represents an arrangement for perforating a piece of or card. It consists of two glass columns, with a horizontal cross-p in which is a pointed conductor, B. The piece of glass, A, is placed an insulating glass support, in which is placed a second condu terminating also in a point, which is connected with the outside of battery, while the knob of the inner coating is brought near the kno B. When the discharge passes between the two conductors the glas perforated. The experiment only succeeds with a single jar when glass is very thin ; otherwise a battery must be used.

The perturbation and sudden expansion which the discharge prod may be illustrated by means of Kinnersley's thermometer. This con of two glass tubes (fig. 582), which fit into metallic caps, and communi with each other. At the top of the large tube is a rod terminating knob, and moving in a stuffing-box, and at the bottom there is a sim rod with a knob. The apparatus contains water up to the level the lower knob. When the electric shock passes between the two kn e water is driven out of the larger tube and rises to a slight extent in e small one. The level is immediately re-established, and therefore the enomenon is not due to an increase of temperature.

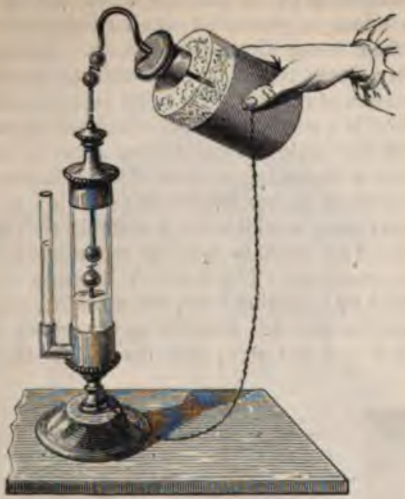


Fig. 582.

For the production of mechanical effects the universal discharger, 570, is of great service. A piece of wood, for instance, placed on the le between the two conductors, is split when the discharge passes.

29. **Chemical effects.**—The chemical effects are the decompositions l recombinations effected by the passage of the electric discharge. ere two gases which act on each other are mixed in the proportions in ich they combine, a single spark is often sufficient to determine their nbination; but where either of them is in great excess, a succession of rks is necessary. Priestley found that when a series of electric sparks s passed through moist air, its volume diminished, and blue litmus roduced into the vessel was reddened. This, Cavendish found, was e to the formation of nitric acid.

Several compound gases are decomposed by the continued action of electric spark. With olefiant gas, sulphuretted hydrogen, and ammia, the decomposition is complete; while carbonic acid is partially omposed into oxygen and carbonic oxide. The electric discharge also suitable means can feebly decompose water, oxides, and salts; but ugh the same in kind, the chemical effects of statical electricity are by means so powerful and varied as those of dynamical electricity. The mical action of the spark is easily demonstrated by means of a ution of iodide of potassium. A small lozenge-shaped piece of filter-paper, impregnated with iodide of potassium, is placed on a glass plate, l one corner connected with the ground. When a few sparks from a conductor charged with positive electricity are taken at the other corner, brown spots are produced, due to the separation of iodine.

Among the chemical effects must be enumerated the formation of *ozone*, which is recognised by its peculiar odour and by certain chemical properties. The odour is perceived when electricity issues through a series of points from a conductor into the air. Its true nature is not accurately known; some regard it, and with great probability, as an allotropic modification of oxygen, and others as a teroxide of hydrogen.

The *electric pistol* is a small apparatus which serves to demonstrate the chemical effects of the spark. It consists of a brass vessel (fig. 583), in which is introduced a detonating mixture of two volumes of hydrogen and one of oxygen, and which is then closed with a cork. In a tubulure in the side there is a glass tube, in which fits a metallic rod, terminated by the knobs A and B. The knob is held as represented in fig. 584, and brought near the machine. The knob A becomes negatively, and B positively electrified by induction from the machine, and a spark passes between the conductor and A. Another spark passes at the same time between the knob B and the side; this determines the combination of the gases, which is accompanied by a great disengagement of heat, and the vapour of water formed acquires such an expansive force, that the cork is projected with a report like that of a pistol.

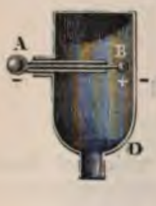


Fig. 583.

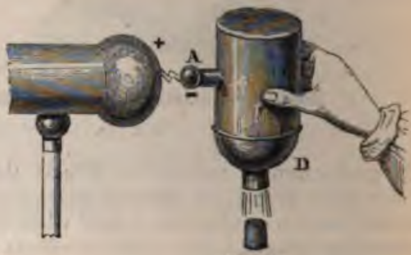


Fig. 584.

mines – 730. **Application of the electrical discharge to firing ~~guns~~.**—By the labours of Prof. Abel in this country, and of Baron von Ebner in Austria, the electrical discharge has been applied to firing mines for military purposes, and the methods have acquired a high degree of perfection. The principle on which the method is based may be understood from the following statement:

One end of an insulated wire in which is a small break is placed in contact with the outside of a charged Leyden jar, the other end being placed near the inner coating. If now this end be brought in contact with the inner coating the jar is discharged and a spark strikes across the break; and if there be here some explosive compound it is ignited, and this ignition may of course be communicated to any gunpowder in which it is placed. If on one side of the break, instead of having an insulated wire direct back to the outer coating of the Leyden jar, an uncovered wire be led into the ground, the outside of the jar being also connected

the ground, the result is unchanged, the earth acting as a return
Moreover, if there be several breaks, the explosion will still ensue
ch of them, provided the charge be sufficiently powerful.

the actual application it is of course necessary to have an arrange-
for generating frictional electricity which shall be simple, portable,
rful, and working in any weather. In these respects the electrical
ine devised by Von Ebner is admirable. Fig. 585 represents a

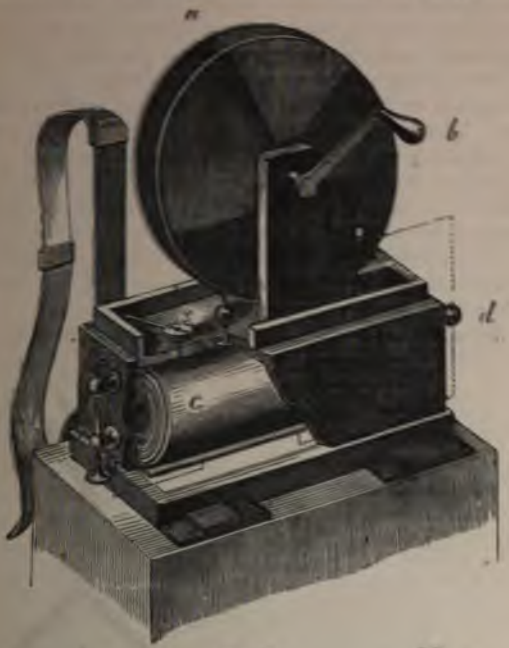


Fig. 585.

of this instrument as constructed by Messrs. Elliott, part of the case
removed to show the internal construction.

consists of two circular plates of ebonite, *a*, mounted on an axis so
they are turned by a handle, *b*, between rubbers, which are so
ged as to be easily removed for the purposes of amalgamation, etc.
ned to a knob on the base of the apparatus and projecting between
plates is a pointed brass rod, which acts as a collector of the
icity. The condenser or Leyden jar arrangement is inside the case,
of which has been removed to show the arrangement. It consists of
-rubber cloth, coated on each side with tinfoil, and formed into a
or the purpose of greater compactness. By means of a metal button
nob is in contact with one tinfoil coating, which thus receives the
icity of the machine, and corresponds to the inner coating of the
en jar. Another button, connected with the other tinfoil coating,

rests on a brass band at the base of the apparatus which is in me contact with the cushions, the knob *d*, and the perforated knob in w slides a rod at the front of the apparatus. These are all in conne with the earth. The knob *e* is in metallic connection with a disc *g* vided with a light arm. By means of a flexible chain this is so conne with a trigger on the side of the apparatus, not represented in the fi that when the trigger is depressed, the arm, and therewith the knob brought into contact with the inner coating of the condenser.

On depressing the trigger, after a certain number of turns, a spark pa between the knob *e* and the sliding rod, and the striking distance measure of the working condition of the instrument.

The fuse used is known as *Abel's electrical fuse*, and has the follo construction. The ends of two fine copper wires, fig. 586, are imbe in a thin solid gutta percha rod, parallel to each other, but at a dist of about 1·5 mim. At the lower end of the gutta percha a small ca paper or tinfoil *cc* is fastened, in which is placed a small quantity of priming composition, which consists of an intimate mixture of subsulp of copper, subphosphide of copper, and chlorate of potassium. paper is fastened down so that the exposed ends of the wires are served in close contact with the powder.

This is the actual fuse; for service the capped end of the fu

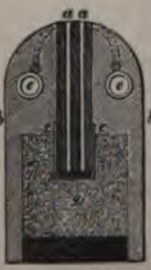


Fig. 586.

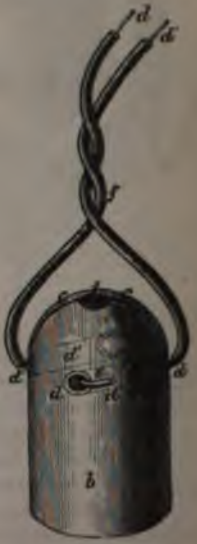


Fig. 587.

placed in a perforation in the rounded head of a wooden cylinder, so project slightly into the cavity *g* of the cylinder. This cavity is filled meal powder which is well rammed down, so that the fuse is f imbedded. It is afterwards closed by a plug of gutta percha, and the whole is finally coated with black varnish.

The free ends of the wires *a a* are pressed into small grooves in the head of the cylinder (fig. 587), and each end is bent into one of the small channels with which the cylinder is provided, and which are at right angles to the central perforation. They are wedged in here by driving in small copper tubes, the ends of which are then filed flush with the surface of the cylinder. The bared ends of two insulated conducting wires are then pressed into one of the small copper tubes or eyes, and fixed there by bending the wire round on to the wood, as shown at *e*.

The conducting wire used in firing may be thin, but it must be well insulated. One end, which is bared, having been pressed into the hole *d* of the fuse, the other is placed in proximity to the exploder. Into the other hole *d′* of the fuse a wire is placed which serves as earth wire, care being taken that there is connection between the two wires. The fuse having been introduced into the charge the earth wire is placed in good connection with the ground. The knob *f* of the exploder is also connected with the earth by leading uncovered wire into water or moist earth, and the condition of the machine tested. The end of the insulated wire is then connected with the knob *e* and the rod drawn down; at the proper signal the handle is turned the requisite number of times, and when the signal is given the trigger is depressed, and the explosion ensues.

When a number of charges are to be fired they are best placed in a single circuit, care being taken that the insulation is good.

731. **Duration of the electric spark. Velocity of electricity.**—Wheatstone has measured the duration of the electric spark, and the velocity of electricity, by means of the rotating mirror, which he invented for this purpose. At some distance from this instrument, which can be made to rotate with a measured velocity, a Leyden jar is so arranged that the spark of its discharge is reflected from the mirror. Now, from the laws of reflection (Note, art. 470) the image of the luminous point describes an arc of double the number of degrees which the mirror describes, in the time in which the mirror passes from the position in which the image is visible to that in which it ceases to be so. If the duration of the image were absolutely instantaneous the arc would be reduced to a mere point. Knowing the number of turns which the mirror makes in a second, and measuring, by means of a divided circle, the number of degrees occupied by the image, the duration of the spark would be determined. In one experiment Wheatstone found that this arc was 24°. Now, in the time in which the mirror traverses 360° the image traverses 720°; but in the experiment the mirror made 800 turns in a second, and therefore the image traversed 576,000° in this time; and as the arc was 24°, the image must have lasted the time expressed by $\frac{24}{576000}$ or $\frac{1}{24000}$ of a second. Thus the discharge is not instantaneous, but has a certain duration, which, however, is excessively short.

Feddersen found that when greater resistances were interposed in the circuit through which the discharge was effected, that the duration of the

spark was increased. With a tube of water 9 mm. in length, the
lasted 0·0014 seconds ; and with one of 180 mm. its duration was o
seconds. The duration increased also with the striking distance,
with the dimensions of the battery.

To determine the velocity of electricity, Wheatstone constructe
apparatus the principle of which will be understood from fig. 588
insulated metal knobs were arranged in a horizontal line on a pie
wood called the *spark board* ; of these the knob 1 was connected wit
outer, while 6 would be connected with the inner coating of a ch
Leyden jar ; the knob 1 was a tenth of an
distant from the knob 2 ; while between 2 a
a quarter of a mile of insulated wire was i
posed ; 3 was likewise a tenth of an inch
4, and there was a quarter of a mile of wire
tween 4 and 5 ; lastly, 5 was a tenth of an
from 6, from which a wire led directly to
outer coating of the Leyden jar. Hence,
the jar was discharged by connecting the
from 6 with the inner coating of the jar, sp
would pass between 1 and 2, between 3 an
and between 5 and 6. Thus the discharge,
posing it to proceed from the inner coating, has to pass in its co
through a quarter of a mile of wire between the first and second s
and through the same distance between the second and third.

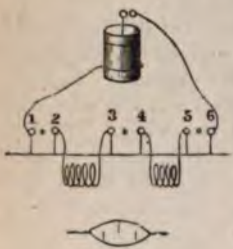


Fig. 588.

The spark board was arranged at a distance of 10 feet from the
ting mirror, and at the same height, both being horizontal ; and
observer looked down on the mirror. Thus the sparks were visible
the mirror made an angle of 45° with the horizon.

Now, if the mirror were at rest or had only a small velocity, the im
of the three sparks would be seen as three dots ⋮, but when the m
had a certain velocity these dots appeared as lines, which were longe
the rotation was more rapid. The greatest length observed was
which, with 800 revolutions in a second, can be shown to correspond
duration of $\frac{1}{24000}$ of a second. With a slow rotation the lines present
appearance ☰ ; they are quite parallel, and the ends in the
line. But with greater velocity, and when the rotation took place
left to right they presented the appearance ☰, and when it tu
from right to left the appearance ☰, because the image of
centre spark was formed after the lateral ones. Wheatstone found
this displacement amounted to half a degree before or behind the ot
This arc corresponds to a duration of $\frac{1}{2 \times 720 \times 800}$ or $\frac{1}{1152000}$ of a sec
the space traversed in this time being a quarter of a mile, gives for
velocity of electricity, 288,000 miles in a second, which is greater
that of light. The velocity of dynamical electricity is far less ; and o
to induction, the transmission of a current through submarine wir
comparatively slow.

In the above experiment the images of the two outer sparks ap neously in the mirror, from which it follows that the electric issues simultaneously from the two coatings of the Leyden jar.

ı certain theoretical considerations based upon measurements of ıt electrical currents, Kirchhoff has concluded that the motion of ity in a wire in which it meets with no resistance is like that of a n a stretched string, and has the velocity $V = \frac{4093159}{\sqrt{2}}$, or 192,924 n a second, which is about that of light in vacuo. According to r, the velocity of electricity is 18,400 miles, and according to Fizeau ounelle, it is 62,100 miles in iron, and 111,780 in copper wire. measurements, however, were made with telegraph wires, which opposite electricities in the surrounding media; there is thus pro- a resistance which diminishes the velocity. The velocity is less re in water than in air. The nature of the conductor appears to ɔme influence on the velocity; but not the thickness of the wire, : tension of the electricity.

atmospheric electricity, reference must be made to the chapter on rology.

BOOK X.

DYN ELECTRICITY.

TER I.

VOLTAI 'S MODIFICATIONS.

732. **Galvani's experi theory.**—The fundamental ex
ment which led to the disco ynamical electricity is due to Gal
professor of anatomy in Bologna. Occupied with investigations on th
fluence of electricity on the nervous excitability of animals, and espec

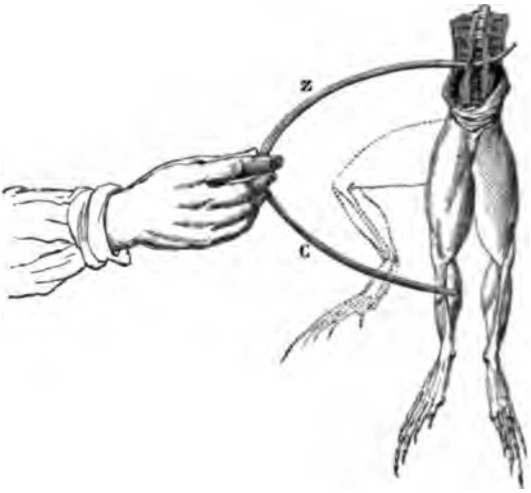


Fig. 589.

of the frog, he observed that when the lumbar nerves of a dead frog
connected with the crural muscles by a metallic circuit, the latter be
briskly contracted.

To repeat this celebrated experiment, the legs of a recently killed
are prepared, and the lumbar nerves on each side of the vertebral cc

exposed in the form of white threads. A metallic conductor, com-
sed of zinc and copper, is then taken (fig. 589), and one end introduced
tween the nerves and the vertebral column, while the other touches one
the muscles of the thighs or legs ; at each contact a smart contraction
the muscles ensues.

Galvani had some time before observed that the electricity of machines
oduced in dead frogs analogous contractions, and he attributed the
enomena first described to an electricity inherent in the animal. He
sumed that this electricity, which he called *vital fluid*, passed from the
rves to the muscles by the metallic arc, and was thus the cause of con-
ction. This theory met with great support, especially among physiolo-
ts, but it was not without opponents. The most considerable of these
s Alexander Volta, professor of physics in Pavia.

733. **Volta's fundamental experiment.**—Galvani's attention had been
lusively devoted to the nerves and muscles of the frog ; Volta's was
ected upon the connecting metal. Resting on the observation, which
lvani had also made, that the contraction is more energetic when the
nnecting arc is composed of two metals than when there is only one,
lta attributed to the metals the active part in the phenomenon of con-
ction. He assumed that the disengagement of electricity was due to
ir contact, and that the animal parts only officiated as conductors, and
he same time as a very sensitive electroscope.

By means of the then recently invented electroscope, Volta devised
eral modes of showing the disengagement of electricity on the contact
metals, of which the following is the easiest to perform :

The moistened finger being placed on the upper plate of a condensing
troscope (fig. 573), the lower plate is touched with a plate of copper, *c*,
lered to a plate of zinc, *z*, which is held in the other hand. On
aking the connection and lifting the upper plate (fig. 574), the gold
ves diverge, and, as may be proved, with negative electricity. Hence,
en soldered together, the copper is charged with negative electricity,
d the zinc with positive electricity. The electricity could not be
e either to friction or pressure ; for if the condenser plate, which
of copper, is touched with the zinc plate *z*, the copper plate to
ich it is soldered being held in the hand, no trace of electricity is
served.

A memorable controversy arose between Galvani and Volta. The
ter was led to give greater extension to his contact theory, and pro-
unded the principle that when *two heterogeneous substances are placed*
contact, one of them always assumes the positive and the other the
ative electrical condition. In this form Volta's theory obtained the
ent of the principal philosophers of his time. Galvani, however, made
umber of highly interesting experiments with animal tissues. In some
hese he obtained indications of contraction, even though the sub-
nces in contact were quite homogeneous.

34. **Disengagement of electricity in chemical actions.**—The
act theory which Volta had propounded, and in which he explained

the action of the pile, soon encountered objectors. Fabroni, a countr man of Volta, having observed that in the pile the discs of zinc becan oxidised in contact with the acidulated water, thought that this oxidati was the principal cause of the disengagement of electricity. In Englar Wollaston soon advanced the same opinion, and Davy supported it many ingenious experiments.

It is true that in the fundamental experiment of the contact theory (7 Volta obtained signs of electricity. But M. de la Rive has shown that the zinc be held in a wooden clamp, all signs of electricity disappear, an that the same is the case if the zinc be placed in gases, such as hydroge or nitrogen, which exert u [illegible] emical action. De la Rive has a cordingly concluded that [illegible] riginal experiment the disengag ment of electricity is due [illegible] ical actions which result from th perspiration and from the [illegible] he atmosphere.

The development of el [illegible] chemical actions may be demon strated in the following m [illegible] ans of the condensing electroscop (718). A disc of moiste [illegible] placed on the upper plate of th condenser, and on this a [illegible] in which some dilute sulphuric aci is poured. A platinum w [illegible] nicating with the ground, but insu lated from the sides of the vessel, is immersed in the liquid, and at th same time the lower plate of the condenser is also connected with th ground by touching it with the moistened finger. On breaking contac and removing the upper plate, the gold leaves are found to be pos tively electrified, proving that the upper plate has received a charge o negative electricity due to the chemical action of the sulphuric acid o the zinc.

By a variety of analogous experiments it may be shown that a chemical actions are accompanied by a disturbance of the electrical equ librium. This is the case whether the substances concerned in th action are in the solid, liquid, or gaseous state, though of all chemica actions those between metals and liquids are the most productive o electricity. All the various resultant effects may be explained on th general principle, that when a liquid acts chemically on a metal th liquid assumes the positive electrical, and the metal the negative electrica condition. In the above experiment the sulphuric acid, by its action o zinc, became positively electrified, and its electricity passed off throug the platinum wire into the ground, while the negative electricity excited in the zinc acted on the condenser just as an excited rod of sealing-wa would have done.

In many cases the electrical indications accompanying chemica actions are but feeble, and require the use of a very delicate electr scope to render them sensible. Thus, one of the most energetic chemic actions, that of sulphuric acid upon zinc, gives no more free electricit than water alone does with zinc. In the former case, both the metal a the liquid are good conductors, and hence the two electricities tend recombine directly at the place of their separation, instead of one passi into the earth and another into the condenser. Only a small port escapes neutralisation, and it is this which the instruments indicate.

it not to confound the electricity generated with the electricity

rent electricity.—When a plate of zinc and a plate of copper ly immersed in dilute sulphuric acid, a disturbance of the equilibrium ensues, for, by means of delicate electroscopic nts, it may be shown that the zinc plate possesses a feeble negative and the copper plate a feeble charge of positive At the same time there is a slight disengagement of hydro- he surface of the zinc. If now the plates be placed in direct , more conveniently, be connected by means of a metallic wire, al action increases, a larger quantity of hydrogen is evolved, drogen is now disengaged from of the copper (fig. 590) ; and if ting wire be examined it will be ssess many remarkable thermal, and other properties, to be here- ibed. So long as the metals the liquid, the opposite electrical of the two plates discharge by means of the wire, but are usly restored, and as rapidly ; and as these successive charges arges take place at such infi- l intervals of time that they may ed continuous, the wire is said to be traversed by an electric *urrent.* The direction of this current *in the connecting wire* to be from the copper to the zinc, or, in other words, this is on in which the positive electricity is supposed to flow, the the negative current in the wire being from the zinc to the ut the existence of this current is purely hypothetical, and taken as more than a convenient mode of explaining the developed in the wire.

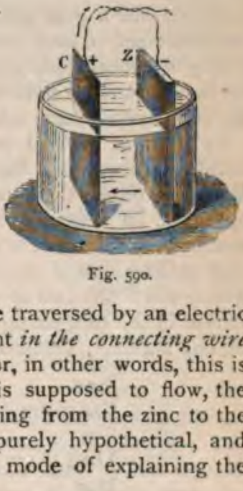


Fig. 590.

taic couple. Electromotive series.—The arrangement just consisting of two metals in metallic contact, and a conducting hich they are placed, constitutes a *simple voltaic element or* long as the metals are not in contact, the couple is said to be hen connected it is *closed.*

roduction of a voltaic current it is not necessary that one of be unaffected by the liquid, but merely that the chemical the one be greater than upon the other. For then, in ac- ith what has been before stated (735), the two metals may be to give rise to two separate currents, of which the one pro- m the metal most attacked is the stronger, and the current therefore the difference between two unequal currents. If ts were absolutely equal, a condition, however, practically to realise, we must assume that no electrical effects would be The metal which is most attacked is called the *positive* or plate, and that which is least attacked the *negative* or *collect-*

ing plate. The positive metal determines the direction of the current, which proceeds *in* the liquid from the positive to the negative *plate*, and *out* of the liquid through the connecting wire from the negative to the positive plate.

In the fundamental experiment, not only the connecting wire but also the liquid and the plates are traversed by the electrical currents—are the scene of electrical actions.

In speaking of the direction of the current the positive current is always understood ; to avoid confusion, the existence of the current in the opposite direction, the negative current, is tacitly ignored.

The mere immersion of two different metals in a liquid is not alone sufficient to produce a current, there must be chemical action. When a platinum and a gold plate are connected with a delicate galvanometer and immersed in pure nitric acid no current is produced ; but on adding a drop of hydrochloric acid a strong current is excited, which proceeds in the liquid from the gold to the platinum, because the gold is attacked by the nitro-hydrochloric acid, while the platinum is less so, if at all.

As a voltaic current is produced whenever two metals are placed in metallic contact in a liquid which acts more powerfully upon one than upon the other, there is great choice in the mode of producing such currents. In reference to their electrical deportment, the metals have been arranged in what is called an *electromotive series*, in which the most *electropositive* are at one end, and the most *electronegative* at the other. Hence when any two of these are placed in contact in dilute acid, the current in the connecting wire proceeds from the one lower in the list to the one higher. The principal metals are as follows:—

Zinc
Cadmium
Tin
Lead
Iron
Nickel
Bismuth
Antimony
Copper
Silver
Gold
Platinum
Graphite

It will be seen that the electrical deportment of any metal depends on the metal with which it is associated. Iron, for example, in dilute sulphuric acid is electronegative towards zinc, but is electropositive towards copper ; copper in turn is electronegative towards iron and zinc, but is electropositive towards silver, platinum, or graphite.

737. **Electromotive force.**—The force produced by the difference in chemical action on two metals in a liquid is called the *electromotive force* ; it is greater in proportion to the distance of the two metals from one another in the series. That is to say, it is greater, the greater the difference between the chemical action upon the two metals immersed. Thus the electromotive force between zinc and platinum is greater than that between zinc and iron, or between zinc and copper. The law established by Poggendorff is, that *the electromotive force between any two metals is equal to the sum of the electromotive forces between all the intervening metals.* Thus the electromotive force between zinc and platinum is equal to the sum of the electromotive forces between zinc and iron, iron and copper, and copper and platinum.

1e electromotive force is influenced by the condition of the metal; d zinc, for instance, is negative towards cast zinc. It also depends 1e degree of concentration of the liquid; in dilute nitric acid zinc is tive towards tin, and mercury positive towards lead; while in conrated nitric acid the reverse is the case, mercury and zinc being ectively electronegative towards lead and tin.

he nature of the liquid also influences the direction of the current. vo plates, one of copper and one of iron, are immersed in dilute sulric acid, a current is set up proceeding through the liquid from the to the copper; but if the plates, after being washed, are placed in tion of sulphide of potassium, a current is produced in the opposite ction, the copper is now the positive metal. Other examples may be vn from the following table, which shows the electric deportment of principal metals with three different liquids. It is arranged like the eding one; each metal being electropositive towards any one lower he list, and electronegative towards any one higher.

Caustic potass	Hydrochloric acid	Sulphide of potassium
Zinc	Zinc	Zinc
Tin	Cadmium	Copper
Cadmium	Tin	Cadmium
Antimony	Lead	Tin
Lead	Iron	Silver
Bismuth	Copper	Antimony
Iron	Bismuth	Lead
Copper	Nickel	Bismuth
Nickel	Silver	Nickel
Silver	Antimony	Iron

voltaic current may also be produced by means of two liquids and metal. This may be shown by the following experiment: In a ker containing strong nitric acid is placed a small porous cylinder ed at one end, and containing strong solution of caustic potass. If two platinum wires connected with the two ends of a galvanometer 4) are immersed respectively in the alkali and in the acid, a voltaic ent is produced, proceeding in the wire from the nitric acid to the ss, which thus corresponds respectively to the negative and positive es in ordinary couple.

metal which is acted upon by a liquid can be protected from solution placing in contact with it a more electropositive metal, and thus forma simple voltaic circuit. This principle is the basis of Davy's proal to protect the copper sheathing of ships, which are rapidly acted n by sea water. If zinc or iron be connected with the copper, these als are dissolved and the copper protected. Davy found that a piece nc the size of a nail was sufficient to protect a surface of forty or fifty are inches, but unfortunately the proposal has not been of practical e, for the copper must be attached to a certain extent to prevent the erence of marine plants and shellfish.

38. **Poles and electrodes.**—If the wire connecting the two terminal es of a voltaic couple be cut, it is clear, from what has been said

about the orgin and direction of the current, that positive electricity will tend to accumulate at the end of the wire attached to the copper or negative plate, and negative electricity on the wire attached to the zinc or positive plate. These terminals have been called the *poles* of the battery. For experimental purposes, more especially in the decomposition of salts, plates of platinum are attached to the ends of the wires. Instead of the term poles the word *electrode* (ἤλεκτρον and ὁδός a way) is now commonly used; for these are the *ways* through which the respective electricities emerge. It is important not to confound the positive *plate* with the positive *pole* or *electrode*. The positive electrode is that connected with the negative plate, while the negative electrode is connected with the positive plate.

739. **Voltaic pile. Voltaic battery.**—When a series of voltaic elements or pairs are arranged in such a manner that the zinc of one element is connected with the copper of another; the zinc of this with the copper of another, and so on, such an arrangement is called a *voltaic battery*; and by its means the effects produced by a single element are capable of being very greatly increased.

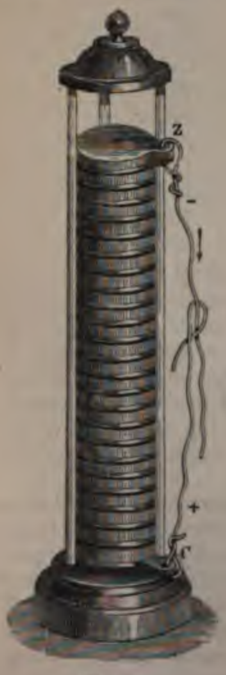


Fig. 591.

The earliest of these arrangements was devised by Volta himself. It consists (fig. 591) of a series of discs piled one over the other in the following order: at the bottom, on a frame of wood, is a disc of copper, then a disc of cloth moistened by acidulated water, or by brine, then a disc of zinc; on this a disc of copper, and another disc of moistened cloth, to which again follow as many sets of zinc-cloth-copper, always in the same order, as may be convenient, the highest disc being of zinc. The discs are kept in vertical positions by glass rods, and it is convenient to have the discs of copper and zinc soldered together as represented in the diagram.

The terminal discs however are single, the one at the top being of zinc and that at the bottom of copper.

It will be readily seen that we have here a series of simple voltaic couples, the moistened disc acting as the liquid, and that the terminal zinc is the negative and the terminal copper the positive pole. From the mode of its arrangement, and from its discoverer, the apparatus is known as the *voltaic pile*, a term applied to all apparatus of this kind for accumulating the effects of dynamical electricity.

The distribution of electricity in the pile varies according as it is in connection with the ground by one of its extremities, or as it is insulated by being placed on a nonconducting cake of resin or glass.

In the former case, the end in contact with the ground is neutral, and he rest of the apparatus only contains one kind of electricity; this is egative if a copper disc is in contact with the ground, and positive if it a zinc disc.

In the insulated pile the electricity is not uniformly distributed. By eans of the proof-plane and the electroscope it may be demonstrated hat the middle part is in a neutral state, and that one-half is charged ith positive and the other with negative electricity, the tension increasg from the middle to the ends. The half terminated by a zinc is harged with negative electricity, and that by a copper with positive lectricity. The pile is thus similar to a charged Leyden jar; with this ifference, however, that when the jar has been discharged by connecting s two coatings, the electrical effects cease; while in the case of the pile, e cause which originally brought about the distribution of electricity stores this state of charge after the discharge; and these successive harges and discharges are continuous; they form the current. The effects f the pile will be discussed in other places.

740. **Wollaston's battery.**—The original form of the voltaic pile has great many inconveniences, and possesses now only an historical terest. It has received a great many improvements, the principal bject of which has been to facilitate manipulation, and to produce reater electromotive force.

One of the earliest of these modifications was the crown of cups, or *uronne des tasses*, invented by Volta himself; an improved form of this known as *Wollaston's battery* (fig. 592); it is arranged so that when e current is not wanted, the action of the battery can be stopped.

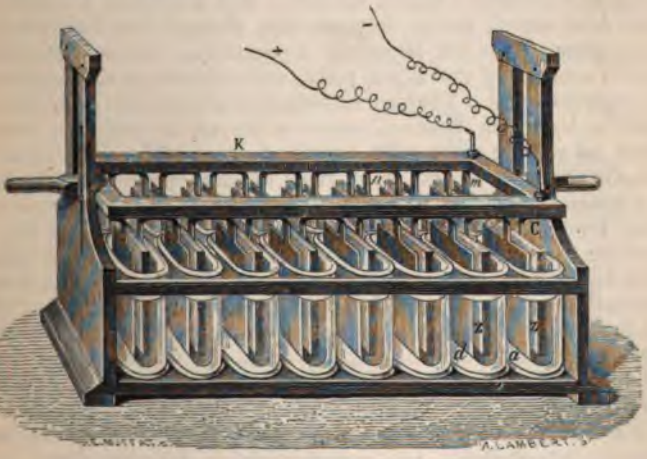


Fig. 592.

The plates Z are of thick rolled zinc, and usually about eight inches length by six in breadth. The copper plates C are of thin sheet, and ent so as to surround the zincs without touching them: contact being

prevented by small pieces of cork. To each copper plate a narro
of copper, *o*, is soldered, which is bent twice at right angles
soldered to the zinc plate; and first zinc Z is surrounded by th
copper C; these two constitute a couple, and each couple is imme
a glass vessel, containing acidulated water. The copper C is sold
the second zinc by the strip *o*, and this zinc is in turn surrounde
second copper, and so on.

Figure 592 represents a pile of sixteen couples united in two p
series of eight each. All these coup'es are fixed to a cross fr
wood, by which they can be raised or lowered at pleasure. Wh
battery is not want lifted out of the liquid. The w
these vessels is usu th $\frac{1}{16}$ sulphuric and $\frac{1}{20}$ of nitric

Hare's deflagrator. nple voltaic arrangement, con
of two large sheets zinc rolled together in a spir
preserved from dire ands of leather or horsehair.
whole is immersed i aining acidulated water, and t
plates are connecte id by a conducting wire.

741. **Enfeeblem ent in batteries. Secondar
rents. Polarity.**— atteries already described,
Wollaston's, and Hare's which consist essentially of two metals a
liquid, labour under the objection that the currents produced
diminish in intensity.

This is principally due to three causes; the first is the decrease
chemical action owing to the neutralisation of the sulphuric acid
combination with the zinc. This is a necessary action, for upon it d
the current; it therefore occurs in all batteries, and is without
except by replacement of acid and zinc. The second is due to
called *local action*; that is, the production of small closed currents
active metal, from the impurities it contains. These local c
rapidly wear away the active plate, without contributing anyth
the general current. They are remedied by amalgamating the zin
mercury, by which chemical action is prevented until the cir
closed, as will be more fully explained (750). The third arise
secondary currents. These are currents which are produced in the
in a contrary direction to the principal current, and which de
either totally or partially. In the fundamental experiment (fig
when the current is closed, sulphate of zinc is formed, which di
in the liquid, and at the same time a layer of hydrogen gas is gr
deposited on the surface of the copper plate. Now it has been
that the hydrogen deposited in this manner on metallic surfaces a
more energetically than ordinary hydrogen. In virtue of this inc
activity it gradually reduces some of the sulphate of zinc formed,
layer of metallic zinc is formed upon the copper; hence, inst
having two different metals unequally attacked, the two metals
gradually less different, and, consequently, in the wire there a
currents tending to become equal; the total effect, and the curren
observed, become weaker and weaker.

The *polarisation* of the plate (as this phenomenon is termed)

·ed by breaking the circuit; the deposit then dissolves, and on closing the circuit the intensity increases. The same result is ·ed when the current of another battery is transmitted in a direction ·te to that of the first.

·a Rive found that when the platinum electrodes which had been · decomposing a liquid were removed from this liquid and placed ·lled water, they produced a current when connected, in a direction ·te to that which they had at first transmitted. He calls this the *·ation of the electrodes.* Becquerel and Faraday have shown that ·larity of the metals results from the deposits produced by secondary ·ts.

·num electrodes, however, which have been used to decompose ·ater, may also become polarised. This phenomenon, as Matteucci ·own, arises from a deposit of hydrogen on the one, and of oxygen · other electrode.

CONSTANT CURRENTS.

Constant currents.—With one or two exceptions, batteries com- ·f elements with a single liquid have gone almost entirely out of use, ·equence of the rapid enfeeblement of the current produced. They ·een replaced by batteries with two liquids, which are called *constant ·s*, because their action is without material alteration for a consider- ·riod of time. The essential point to be attended to in securing a ·nt current is to prevent the polarisation of the inactive metal; in ·ords, to hinder any permanent deposition of hydrogen on its sur- This is effected by placing the inactive metal in a liquid upon the deposited hydrogen can act chemically.

Daniell's battery.—This was the first form of the constant ·, and was invented by Daniell in the ·36. As regards the constancy of its · it is still the best of all constant ·es. Fig. 593 represents a single ·t. A glass or porcelain vessel, V, con- ·a saturated solution of sulphate of ·, in which is immersed a copper ·r, C, open at both ends, and per- · by holes. At the upper part of this ·r there is an annular shelf, G, also ·ted by small holes, and below the ·f the solution: this is intended to ·t crystals of sulphate of copper to · that decomposed as the electrical · proceeds. Inside the cylinder is a ·orous vessel, P, of unglazed earth- ·. This contains either solution of common salt or dilute sulphuric · which is placed the cylinder of amalgamated zinc, Z. Two thin ·of copper, *p* and *n*, fixed by binding screws to the copper and ·zinc, serve for connecting the elements in series.

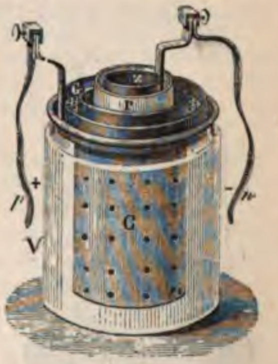


Fig. 593.

When a Daniell's element is closed, the hydrogen resulting from the action of the dilute acid on the zinc is liberated on the surface of the copper plate, but meets there the sulphate of copper, which is reduced, forming sulphuric acid and metallic copper, which is deposited on the surface of the copper plate. In this way sulphate of copper in solution is taken up, and if it were all consumed, hydrogen would be deposited on the copper, and the current would lose its constancy. This is prevented by the crystals of sulphate of copper which keep the solution saturated. The sulphuric acid produced by the decomposition of the sulphate permeates the porous cylinder, and tends to replace the acid used up by its action on the zinc; and as the quantity of sulphuric acid formed in the solution of sulphate of copper is regular, and proportional to the acid used in dissolving the zinc, the action of this acid on the zinc is regular also, and thus a constant current is produced.

In order to join together several of these elements to form a battery, the zinc of one is connected either by a copper wire or strip with the copper of the next, and so on, from one element to another, as shown in fig. 597, for another kind of battery.

Instead of a porous vessel a bag of sailcloth may be used for the diaphragm separating the two liquids. The effect is at first more powerful, but the two solutions mix more rapidly, which weakens the current. The object of the diaphragm is to allow the current to pass, but to prevent as much as possible the mixture of the two liquids.

The current produced by a Daniell's battery is constant for some hours; its action is stronger when it is placed in hot water.

744. **Grove's battery.**—In this battery the sulphate of copper solution is replaced by nitric acid, and the copper by platinum, by which greater electromotive force is obtained. Fig. 594 represents one of the forms of a couple of this battery. It consists of a glass vessel, A, partially filled with dilute sulphuric acid (1 : 8); of a cylinder of zinc, Z, open at both ends; of a vessel, V, made of porous pipeclay, and containing ordinary nitric acid; of a plate of platinum, P (fig. 595), bent in the form of an S, and fixed to a cover, *c*, which rests on the porous vessel. The platinum is connected with a binding screw, *b*, and there is a similar binding screw on the zinc. In this battery the hydrogen, which would be disengaged on the platinum, meeting the nitric acid, decomposes it, forming hyponitrous acid, which dissolves or is disengaged as nitrous fumes. Grove's battery is the most convenient and one of the most powerful of the two-fluid batteries. It is, however, the most expe

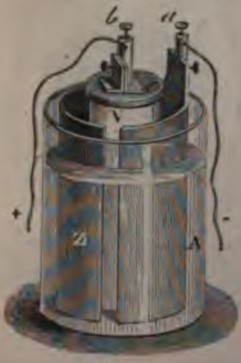


Fig. 594.

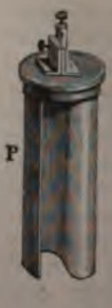


Fig. 595.

sive, owing to the high price of platinum ; besides which the platinum is liable, after some time, to become brittle and break very easily. But as the platinum is not consumed, it retains its value ; and when the plates which have been used in a battery are heated to redness, they retain their elasticity.

745. **Bunsen's battery.**—*Bunsen's battery*, also known as the *zinc carbon* battery, was invented in 1843 ; it is nothing more than Grove's battery, in which the sheet of platinum is replaced by a cylinder of carbon. This is made either of the graphitoidal carbon deposited in gas retorts, or by calcining in an iron mould an intimate mixture of coke and bituminous coal, finely powdered and strongly compressed. Both these modifications of carbon are good conductors. Each element consists of he following parts : 1. a vessel, F (fig. 596), either of stoneware or of glass, containing dilute sulphuric acid ; 2. a hollow cylinder, Z, of amalgamated zinc ; 3. a porous vessel, V, in which is ordinary nitric acid ; 4.

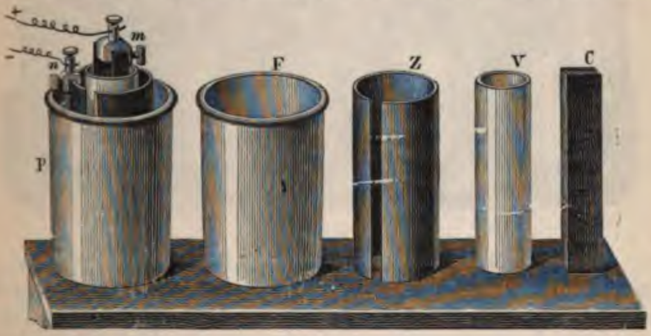


Fig. 596.

cylinder of carbon, C, prepared in the above manner. In the vessel F he zinc is first placed, and in it the carbon as seen in P. To the carbon s fixed a binding screw, *m*, to which a copper wire is attached, forming he positive pole. The zinc is provided with a similar binding screw, *n*, nd wire, which is thus a negative pole.

The elements are arranged to form a battery by connecting each carbon o the zinc of the following one by means of the clamps *mn* and a strip of opper *c* represented in the top of the figure. The copper is pressed at ne end between the carbon and the clamp, and at the other it is soldered o the clamp *n* which is fitted on the zinc of the following element, and so orth. The clamp of the first carbon and that of the last zinc are alone rovided with binding screws to which are attached the wires.

The chemical action of Bunsen's battery is the same as that of Grove's, nd being equally powerful, while less costly, is almost universally used n the Continent. But though its first cost is less than that of Grove's attery, it is more expensive to work, and is not so convenient to manipulate.

Callan's battery is a modified form of Grove's. Instead of zinc and platinum, zinc and platinised lead are used, and instead of pure nitric ac Callan uses a mixture of sulphuric acid, nitric acid, and saturated soluti of nitre. The battery is said to be equal in its action to Grove's, and much cheaper.

Callan has also constructed a battery in which zinc in dilute sulphuri acid forms the positive plate, and cast iron in strong nitric acid the neg tive. Under these circumstances the iron becomes passive; it is strong electronegative, and does not dissolve. If, however, the nitric acid becom

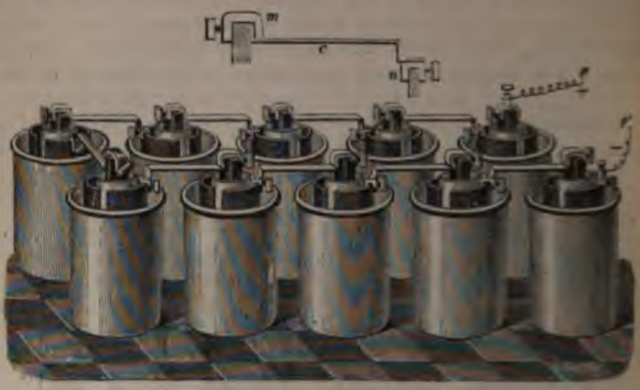


Fig. 597.

too weak, the iron is dissolved with simultaneous disengagement of nitr fumes.

After being in use some time, all the batteries in which the polarisatio is prevented by nitric acid disengage nitrous fumes in large quantitie and this is a serious objection to their use, especially in closed rooms. T prevent this, nitric acid is frequently replaced by chromic acid, or bett by a mixture of 4 parts bichromate of potassium, 4 parts sulphuric aci and 18 water. The liberated hydrogen reduces the chromic acid to th state of oxide of chromium, which remains dissolved in sulphuric aci With the same view, sesquichloride of iron is sometimes substituted f nitric acid; it becomes reduced to protochloride. But the action of th elements thus modified is considerably less than when nitric acid is use owing to the increased resistance.

746. **Smee's battery.**—In this battery the polarisation of the nega plate is prevented by mechanical means. Each element consists of sheet of platinum placed between two vertical plates of zinc, as in Grov battery; but as there is only a single liquid, dilute sulphuric acid, the el ments have much the form of those in Wollaston's battery. The adheren of hydrogen to the negative plate is prevented by covering the platin with a deposit of finely divided platinum. In this manner the surface roughened, which facilitates the disengagement of hydrogen to a remar able extent, and, consequently, diminishes the resistance of the coupl

tead of platinum, silver covered with a deposit of finely divided plaım is frequently substituted, as being cheaper.

Valker's battery.—This resembles Smee's battery, but the electroative plate is either gas graphite or platinised graphite; it is excited dilute sulphuric acid. This battery is used in all the stations of the ıth Eastern Railway, and promises to come into more extensive use, it has considerable electromotive force; it is convenient and econoal in manipulation, and large-sized elements can be constructed at a ap rate.

47. **Recent batteries.**—The *sulphate of mercury* battery (fig. 598) ded by M. Marié Davy, is essentially a zinc-carbon element, but of smaller

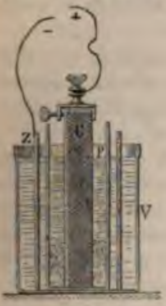


Fig. 598.

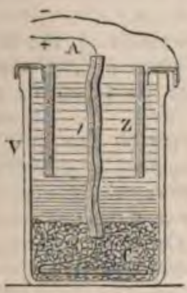


Fig. 599.

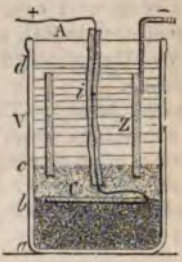


Fig. 600.

ensions than those elements usually are. In the outer vessel V ordinary er or brine is placed, and in the porous vessel sulphate of mercury. s salt is agitated with about three times its volume of water, in which difficultly soluble, and the liquid poured off from the pasty mass. The on being placed in the porous vessel the spaces are filled with the due and then the decanted liquid poured into it.

hemical action takes place only when the pile is closed. The zinc decomposes the water, liberating hydrogen, which traversing the ous vessel reduces the sulphate of mercury, forming metallic mercury, ch collects at the bottom of the vessel, while the sulphuric acid formed he same time traverses the diaphragm to act on the zinc and thus inses the action. The mercury which is deposited may be used to pree a quantity of sulphate equal to that which has been consumed. A ll quantity of the solution of sulphate of mercury may also pass through diaphragm; but this is rather advantageous, as its effect is to amalgae the zinc.

he electromotive force of this element is about a quarter greater than of Daniell's element, but it has greater resistance; it is rapidly exsted when continuously worked, though it appears well suited for distinuous work, as with the telegraph, and with alarums.

ravity batteries. The use of porous vessels is liable to many objecs, more especially in the case of Daniell's battery, in which they lually become encrusted with copper, which destroys them. A kind of battery has been devised in which the porous vessel is entirely dispensed with, and the separation of the liquids is effected by their difference of density. Such batteries are called *gravity batteries*; the one in use at the telegraphic establishment of the Royal Engineers at Chatham is based on this principle.

Figure 599 represents a form devised by M. Callaud of Nantes. *V* is a glass or earthenware vessel in which is a copper plate soldered to a wire insulated by gutta percha. On the plate is a layer of crystals of sulphate of copper C; the whole is then filled with water, and the zinc cylinder *Z* is immersed in it. The lower part of the liquid becomes saturated with sulphate of copper; the actio ery is that of a Daniell, and the sulphate of zinc which gradua oats on the solution of sulphate of copper owing to its lower de

This battery is easily r , the consumption of sulphate of copper is economical, and agitated it works constantly for some months, provided en to replace the water lost by evaporation.

Menotti's battery.—This scribed as a Daniell's element, in which the porous vessel is a layer of sawdust or of sand. At the bottom of an earthenware vessel (fig. 610) is placed a layer of coarsely-powdered sulphate of copper *a*, and on this a copper plate provided with an insulated copper wire *i*. On this there is a layer of sand or of sawdust *bc*, and then the whole is filled with water in which rests a zinc cylinder *Z*. The action is just that of a Daniell; the sawdust prevents the mixture of the liquids but it also offers great resistance, which increases with its thickness.

This battery is coming into use for telegraphic work, and from its simplicity and economy, and the facility with which it is constructed, merits increased attention.

Leclanché's elements consist of a rod of carbon placed in a porous pot, which is then tightly packed with a mixture of pyrolusite (peroxide of manganese) and coke. The porous pot is contained in an outer vessel in which is the electropositive element the zinc. The exciting liquid is a solution of sal ammoniac; it is advantageous not to fill the vessel more than one-third with the liquid. The battery is coming into very extended use; its electromotive force is about $\frac{9}{10}$ that of a Daniell, and its resistance about $1\frac{1}{4}$ of a British Association unit.

748. **Electromotive force of different elements.**—The following values have been obtained for the electromotive force of the most usual combinations; they are the means of many careful determinations.

Bunsen's element	839
Grove's „	829
Daniell's „	470
Smee's „	210
Wollaston's „	208

749. **Tension of the battery.**—The tension of the battery is us defined as being the tendency of the electricity accumulated at the

tremities to free itself, and to overcome the obstacles offered to its passage. It is proportional to the electromotive force : thus the tension of a zinc-carbon battery is greater than that of a zinc-copper battery. The tension of a battery must not be confounded with the *quantity* of electricity which it can disengage. The tension of a battery is proportional to the number of couples, while the quantity, other things being equal, is proportional to their surface. The larger this surface the greater is the quantity of electricity which flows in the circuit. This quantity also increases with the conductivity of the liquid interposed between the couples ; the tension on the contrary is independent of the nature of this liquid.

Except in the case of a very considerable number of couples, the tension at the extremities of the battery is always far weaker than in electrical machines.

Gassiott's great battery, which consisted of 3520 zinc and copper elements, with poles $\frac{1}{50}$ of an inch apart, gave a series of sparks across this nterval which lasted for weeks.

By means of a delicate condensing electroscope, and by extremely careful insulation, the tension of a battery and even of a single cell may be observed. For this purpose one of the plates of the electroscope is connected with one end of the pile, and the other with the other end or with the ground. The apparatus is then charged, and on breaking the communications electroscopic indications are observed. A Leyden jar may even be charged when the interior coating is connected with one end of the pile, and the external coating with the other ; but the tension of this charge s far feebler than that furnished by an electrical machine.

On the other hand, the quantity of electricity which is furnished by a voltaic element is very great as compared with that of the machine. Faraday immersed two wires, one of zinc, and the other of platinum, each $\frac{1}{13}$ of an inch in diameter, in acidulated water for $\frac{3}{20}$ of a second. The effect thus produced on a magnetic needle in this short time was greater than that produced by 23 turns of the large electrical machine of the Royal Institution.

750. **Amalgamated zinc. Local currents.**—De la Rive observed that perfectly pure distilled zinc was not attacked by dilute sulphuric acid, but became so when immersed in that liquid in contact with a plate of copper or of platinum. Ordinary commercial zinc, on the contrary, is rapidly dissolved by dilute acid. This, doubtless, arises from the impurity of the zinc, which always contains traces either of iron or lead. Being electronegative towards zinc they tend to produce *local electrical currents*, which accelerate the chemical action without increasing the quantity of electricity n the connecting wire.

Zinc, when amalgamated, acquires the properties of perfectly pure zinc and is unaltered by dilute acid, so long as it is not in contact with a copper or platinum plate immersed in the same liquid. To amalgamate a zinc plate, it is first immersed in dilute sulphuric or hydrochloric acid so as to obtain a clean surface, and then a drop of mercury is placed on the plate and spread over it with a brush. The amalgamation takes place immediately, and the plate has the brilliant aspect of mercury.

Zinc as well as other metals are readily amalgamated by dipping them in an amalgam of one part sodium and 200 parts of mercury.

Zinc plates may also be amalgamated by dipping them in a solution of mercury prepared by dissolving at a gentle heat one pound of mercury in five pounds of aqua regia (one part of nitric to three of hydrochloric acid), and then adding five parts more of hydrochloric acid.

The amalgamation of the zinc removes from its surface all the impurities, especially the iron. The mercury effects a solution of pure zinc, which covers the surface of the plate, as with a liquid layer.

The amalgamation of zinc was first applied to electrical batteries by Kemp. Amalgamated zinc is not attacked so long as the circuit is not closed, that is, when there is no current. With amalgamated zinc the current is more regular, and at the same time more intense, for the same quantity of metal dissolved.

751. **Dry piles.**—In *dry piles* the liquid is replaced by a solid hygrometric substance, such as paper or leather. They are of various kinds: in Zamboni's, which is most extensively used, the electromotors are tin or silver, and binoxide of manganese. To construct one of these a piece of paper silvered or tinned on one side is taken; the other side of the paper is coated with finely-powdered binoxide of manganese by slightly moistening it, and rubbing the powder on with a cork. Having placed together seven or eight of these sheets, they are cut by means of a punch into discs an inch in diameter. These discs are then arranged in the same order, so that the tin or silver of each disc is in contact with the manganese of the next. Having piled up, 1,200 to 1,800 couples, they are placed in a glass tube; which is provided with a brass cap at each end. In each cap there is a rod and knob, by which the leaves can be pressed together, so as to produce better contact. The knob in contact with the manganese corresponds to the positive pole, while that at the other end, which is in contact with the silver or tin, is the negative pole.

The dry piles are remarkable for the permanence of their action, which may continue for several years. Their action depends greatly on the temperature and on the hygrometric state of the air. It is stronger in summer than in winter, and the action of a strong heat revives it when it appears extinct. A Zamboni's pile of 2,000 couples gives neither shock nor spark, but can charge a Leyden jar and other condensers. A certain time is however necessary, for electricity only moves slowly in the interior.

752. **Bohnenberger's electroscope.**—Bohnenberger has constructed a dry-pile electroscope of extreme delicacy. It is a condensing electroscope (fig. 573), from the rod of which is suspended a single gold leaf. This is at an equal distance from the opposite poles of two dry piles placed vertically, inside the bell jar, on the plate of the apparatus. As soon as the gold leaf possesses any free electricity it is attracted by one of the poles and repelled by the other, and its electricity is obviously contrary to that of the pole towards which it moves.

CHAPTER II.

DETECTION AND MEASUREMENT OF VOLTAIC CURRENTS.

753. **Detection and measurement of voltaic currents.**—The remarkable phenomena of the voltaic battery may be classed under the heads physiological, chemical, mechanical, and physical effects; and these latter may be again subdivided into the thermal, luminous and magnetic effects. For ascertaining the existence and measuring the intensity of voltaic currents, the magnetic effects are more suitable than any of the others, and, accordingly, the fundamental magnetic phenomena will be described here, and the description of the rest postponed to a special chapter on electro-magnetism.

754. **Oersted's experiment.**—Oersted published in 1819 a discovery which connected magnetism and electricity in a most intimate manner, and became, in the hands of Ampère and of Faraday, the source of a new branch of physics. The fact discovered by Oersted is the directive action which a fixed current exerts at a distance on a magnetic needle.

To make this experiment a copper wire is suspended horizontally in the direction of the magnetic meridian over a moveable magnetic needle, as represented in fig. 601. So long as the wire is not traversed by a current the needle remains parallel to it, but as soon as the ends of the wire are respectively connected with the poles of a battery or of a single element, *the needle is deflected, and tends to take a position which is the more nearly at right angles to the magnetic meridian in proportion as the current is more intense.*

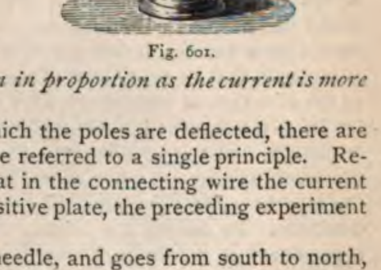


Fig. 601.

In reference to the direction in which the poles are deflected, there are several cases which may, however, be referred to a single principle. Remembering our assumption (722), that in the connecting wire the current proceeds from the negative to the positive plate, the preceding experiment presents the following four cases :—

i. If the current passes above the needle, and goes from south to north, the north pole of the magnet is deflected towards the west; this arrangement is represented in the above figure.

ii. If the current passes below the needle, also from south to north, the north pole is deflected towards the east.

iii. When the current passes above the needle, but from north to south, the north pole is deflected towards the east.

iv. Lastly, the deflection is towards the west when the current goes from north to south below the needle.

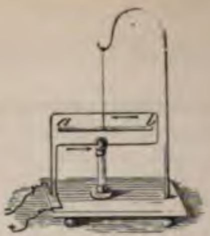


Fig 602.

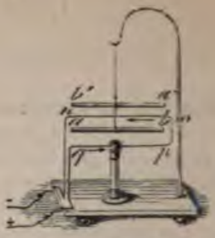


Fig. 603.

Ampère has given the following *memoria technica* by which all the various directions of the needle under the influence of a current may be remembered. If we imagine an observer placed in the connecting wire in such a manner that the current entering by his feet issues by his head, and that his face is always turned towards the needle, we shall see that in the above four positions the north pole is always deflected towards the left of the observer. By thus personifying the current, the different cases may be comprised in this general principle : *In the directive action of currents on magnets, the north pole is always deflected towards the left of the current.*

755. **Galvanometer or multiplier.**—The name *galvanometer*, or sometimes *multiplier* or *rheometer*, is given to a very delicate apparatus by which the existence, direction, and intensity of currents may be determined. It was invented by Schweigger in Germany a short time after Oersted's discovery.

In order to understand its principle, let us suppose a magnetic needle suspended by a filament of silk (fig. 602), and surrounded in the plane of the magnetic meridian by a copper wire, forming a complete circuit round the needle in the direction of its length. When this wire is traversed by a current, it follows, from what has been said in the previous paragraph, that in every part of the circuit an observer lying in the wire in the direction of the arrows, and looking at the needle *ab*, would have his left always turned towards the same point of the horizon, and consequently, that the action of the current in every part would tend to turn the north pole in the same direction : that is to say, that the actions of the four branches of the circuit concur to give the north pole the same direction. By coiling the copper wire in the direction of the needle, as represented in the figure, the action of the current has been *multiplied.* If instead of a single one, there are several circuits, provided they are insulated, the action becomes still more multiplied, and the deflection of the needle increases. Nevertheless, the action of the current cannot be multiplied indefinitely by increasing the number of windings, for, as we shall presently see, the intensity of a current diminishes as the length of the circuit is increased.

ion of the earth continually tends to keep the needle idian, and thus opposes the action of the current, the is increased by using an astatic system of two needles, 603. The action of the earth on the needle is then very the actions of the current on the two needles become in fact, the action of the circuit, from the direction of the ed by the arrows, tends to deflect the north pole of the ards the west. The upper needle $a'b'$, is subjected to the ntrary currents mn and qp, but as the first is nearer, its ates. Now this current passing below the needle, evi- turn the pole a' towards the east, and, consequently, the the west: that is to say, in the same direction as the pole needle.

principles it will be easy to understand the theory of the The apparatus represented in fig. 604 consists of a thick D, resting on levelling screws; on this is a rotatory plate, P, metal, to which is fixed a copper frame, the breadth of which

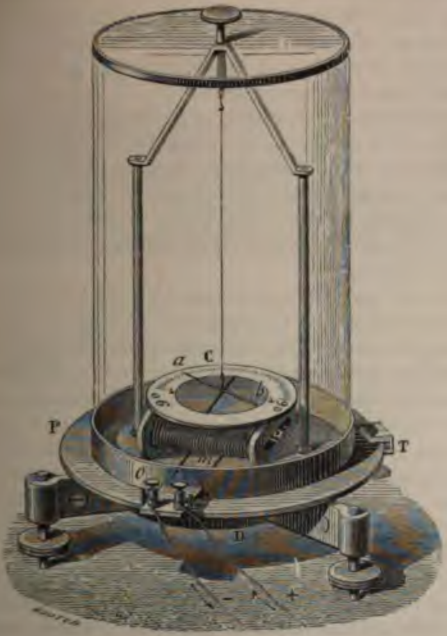


Fig. 604.

equal to the length of the needles. On this is coiled a great f turns of wire covered with silk. The two ends terminate in rews, i and o. Above the frame is a graduated circle, C, with a central slit parallel to the direction in which the wire is coiled. The zero corresponds to the position of this slit, and there are two graduations on the scale, the one on the right and the other on the left of zero, but they only extend to 90°. By means of a very fine filament of silk, an astatic system is suspended; it consists of two needles, *ab* and *a'b'*, one above the scale, and the other within the circuit itself. These needles, which are joined together by a copper wire, like those in fig. 517 and fig. 603, and cannot move separately, must not have exactly the same magnetic intensity; for if they are exactly equal, every current, strong or weak, would always put them at right angles with itself.

In using this instrument, the diameter, to which corresponds the zero of the graduation, is brought into the magnetic meridian by turning the plate P until the end of the needle *ab* corresponds to zero. The instrument is fixed in this position by means of the screw clamp T.

The length and diameter of the wire vary with the purpose for which the galvanometer is intended. For one which is to be used in observing the currents due to chemical actions, a wire about $\frac{1}{6}$ millimeter in diameter, and making about 800 turns, is well adapted. Those for thermo-electric currents, which have low intensity, require a thicker and shorter wire, for example, thirty turns of a wire $\frac{2}{3}$ millimeter in diameter. For very delicate experiments, as in physiological investigations, galvanometers with as many as 30,000 turns have been used.

By means of a delicate galvanometer consisting of 2,000 or 3,000 turns of fine wire, the coils of which are carefully insulated by means of silk and shellac, currents of high intensity, as those of the electrical machine, may be shown. One end of the galvanometer is connected with the conductor and the other with the ground, and on working the machine the needle is deflected; affording thus an illustration of the identity of statical with dynamical electricity.

The deflection of the needle increases with the intensity of the current; the relation between the two is, however, so complex, that it cannot well be deduced from theoretical considerations, but requires to be determined experimentally for each instrument. And in the majority of cases the instrument is used rather as a *galvanoscope* or *rheoscope*, that is, to ascertain the presence and direction of currents, than as a *galvanometer* or *rheometer* in the strict sense, that is, as a measurer of their intensity. The latter term *galvanometer* is, however, commonly used.

The *differential galvanometer* consists of a needle, as in an ordinary galvanometer, but round the frame of which are coiled two wires of the same kind and dimensions, carefully insulated from each other, and provided with suitable binding screws, so that separate currents can be passed through each of them. If the currents are of the same intensity but in different directions, no deflection is produced; where the needle is deflected one of the currents differs from the other. Hence the apparatus is used to ascertain a difference in intensity of two currents and to this circumstance owes its name.

756. **Sir W. Thomson's marine galvanometer.**—In laying submarine cables the want was felt of a galvanometer sufficiently sensitive to test

cted by the pitching and
mson invented his
this instrument
coil of many
ed throughout,
this coil is a
h is represented
of a piece of fine
es not weigh more
ghtly concave mirror
k is stretched across
to it in such a manner

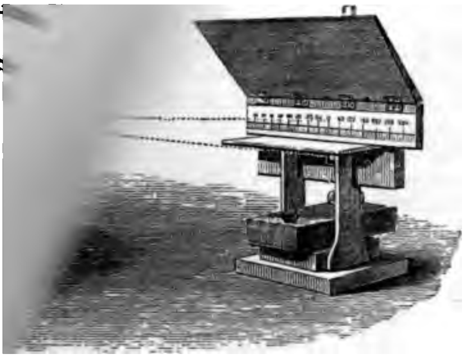


Fig. 605.

passes through the centre of gravity in every
ror and magnet weigh only a few grains, they
respecting the instrument, however the ship may
e slide fits in a groove in the coil, and the whole
a wrought iron case with an aperture in front, and
d on the top. The object of this is to counteract
the terrestrial magnetism when the ship changes its

the coil is a large curved steel magnet N, which compen-
h's directive action upon the magnet D, and in the side of
on a level with D, a pair of magnets are placed with oppo-
gether. By a screw, suitably adjusted, the poles of the magnets
ght together; in which case they quite neutralise each other,
ert no action on the suspended magnet, or they may be slid
each other in such a manner that the action of either pole on
rates to any desired extent. This small magnet is then
very delicate adjustment. The large magnet N, and the pair

of magnets C, are analogous to the coarse and fine adjustr microscope.

At a distance of about three feet, there is a scale with the ze centre and the graduation extending on each side. Underneath point is a narrow slit, through which passes the light of a paraff and which traversing the window is reflected from the curv against the graduated scale. By means of the adjusting ma image of the slit is made to fall on the centre of the graduation.

This being the case, if any arrangement for producing a current weak be connected with the terminals, the spot of light is deflec to one side or the other, according to the direction of the cur stronger the current the greater the deflection of the spot; a current remains of constant strength for any length of time, th stationary in a corresponding position.

The movement on a screen of a spot of light reflected from the most delicate and convenient means of observing motions themselves are too small for direct measurement or observation. H principle is frequently applied in experimental investigation and i illustration. It is used in observing the motion of vibratin in measuring the variations of magnetism, in determining the e of solids, &c. &c.

It will be seen from the article on the Electric Telegraph, h nate deflections of the spot of light may be utilised in forming a signals.

757. **Tangent compass, or tangent galvanometer.**—When a

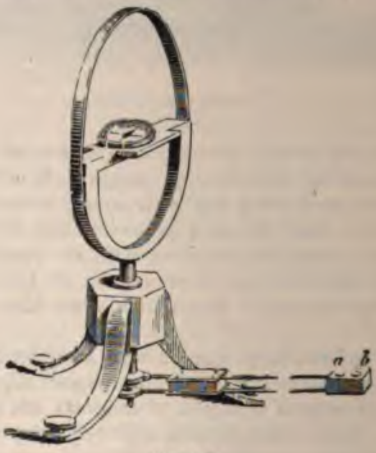


Fig. 606.

needle is suspended in the centre of a voltaic current in the plan magnetic meridian, it can be proved that the intensity of a cu rectly proportional to the tangent of the angle of deflection, provided the mensions of the needle are sufficiently small as compared with the ameter of the circuit. An instrument based on this principle is called e *tangent galvanometer*, or *tangent compass*. It consists of a copper ng. 12 inches in diameter, and about an inch in breadth, mounted rtically on a stand; the lower half of the ring is generally fitted in a micircular frame of wood to keep it steady. In the centre of the ring suspended a delicate magnetic needle whose length must not exceed or $\frac{1}{10}$ of the diameter of the circle. Underneath the needle there is a aduated circle. The ends of the ring are prolonged in copper wires, ted with mercury cups, *ab*, by which it can be connected with a battery element. The circle is placed in the plane of the magnetic meridian, d the deflection of the needle is directly read off on the circle, and its rresponding value obtained from a table of tangents.

On account of its small resistance, the tangent compass is well adapted r currents of low tension, but in which a considerable quantity of elec-city is set in motion. For currents which can overcome great resist-ce, but have only a small quantity of electricity, the multiplier is best ted.

To prove that the intensities of various currents are proportional to e tangents of the corresponding angles of deflection, let NS represent e wire of the galvanometer and *ns* the needle, and ϕ be the angle of deflection produced when a rrent C is passed. Two forces now act upon the edle—the force of the earth's magnetism, which we ll denote by T, which tends to place the needle in e magnetic meridian, and the force of the current C ich strives to place it at right angles to the mag-tic meridian. Let the magnitudes of these forces represented by the corresponding lines *an* and *bn*. ow the whole intensities of these forces do not act as to turn the point of the needle round, but only ose components which are at right angles to the edle. Resolving them we have *ng* and *nf* as the ces acting in opposite directions on the needle; d since the needle is at rest these forces must be ual.

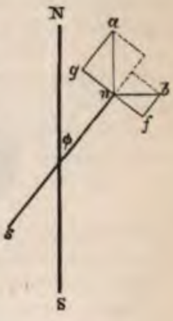


Fig. 607.

The angle *nag* is equal to the angle ϕ, and therefore $ng = an \sin \phi$; and like manner the angle *bnf* is equal to ϕ and $nf = bn \cos \phi$; and there-e since $nf = ng$, $bn \cos \phi = an \sin \phi$, or $bn = an \frac{\sin \phi}{\cos \phi} = an \tan \phi$, that is, $= \mathrm{T} \tan \phi$.

If any other current be passed through the galvanometer we shall have nilarly $\mathrm{C}' = \mathrm{T} \tan \phi'$; and since the earth's magnetism does not alter one and the same place $\mathrm{C} : \mathrm{C}' = \tan \phi : \tan \phi'$.

In this reasoning it has been assumed that the action of the current on needle is the same whatever be the angle in which it is deflected.

This is only the case when the dimensions of the needle are small
pared with the diameter of the ring; it should not be more than
the diameter. In order to measure with accuracy the deflections a
index is placed at right angles to the needle.

758. **Sine compass.**—This is another form of galvanometer
measuring powerful currents. Round the circular frame, M, fig.
several turns of stout insulated copper wire are coiled, the two
which, *i*, terminate in the binding screws at E. On a table in the
of the ring there is a magnetic needle, *m*; a second light needle,

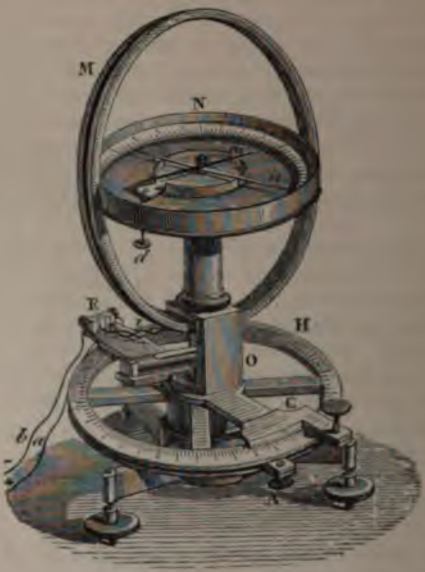


Fig. 608

to the first, serves as pointer along the graduated circle, N. Two
wires, *a b*, from the sources of electricity to be measured, are con
with E. The circles M and N are supported on a foot O whic
move about a vertical axis passing through the centre of a fixed hor
circle H.

The circle M being then placed in the magnetic meridian, and
fore in the same plane as the needle, the current is allowed to pass.
needles being deflected, the circuit M is turned until it coincide
the vertical plane passing through the magnetic needle *m*. The di
action of the current is now exerted perpendicularly to the direc
the magnetic needle, and it may be shown that the intensity
current is proportional to the sine of the angle of deflection; this
is measured on the circle H by means of a vernier on the pi

piece, C, fixed to the foot O, turns it by means of a knob, A. The
of deflection, and hence its sine, being
n, the intensity of the current may be
deduced; let mm' be the direction of
agnetic meridian, d the angle of deflec-
I the intensity of the current, and T the
ive action of the earth. If the direction
ntensity of this latter force be represented
, it may be replaced by two components,
d ac, fig. 609. Now, as the first has no
ive action on the needle, the component
ust alone counterpoise the force I, that is,
. But in the triangle, ack, $ac = ak$, cos.
rom which $ac = T \sin. d$, for the angle
s the complement of the angle d, and ak
al to T; hence, lastly, $I = T \sin. d$, which

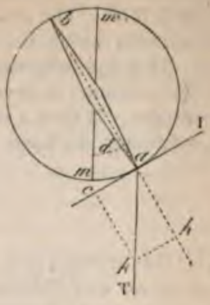


Fig. 609.

o be proved. In like mannner for any other current I′ which produces
lection d', we shall have $I' = T \sin d'$, whence $I : I' = \sin d : \sin d'$.

). **Ohm's law.**—For a knowledge of the conditions which regulate
ction of the voltaic current, science is indebted to the late Professor
. His results were at first deduced from theoretical considerations; but
is own researches, as well as by those of Fechner, Pouillet, Daniell,
a Rive, Wheatstone, and others, they have received the fullest con-
ation, and their great theoretical and practical importance has been
established.

The force or cause by which electricity is set in motion in the voltaic
it is called the *electromotive force*. The quantity of electricity which
y unit of time flows through a section of the circuit is called the *in-*
ty of the current. Ohm found that this intensity is the same in all
of one and the same circuit, however heterogeneous they were; and
that it is proportional to the electromotive force.

has further been found that when the same current is passed respec-
y through a short and through a long wire of the same material, its
n on the magnetic needle is less in the latter case than in the former.
accordingly supposed that in the latter case there was a greater *re-*
nce to the passage of the current than in the former; and he proved
'*the resistance is inversely proportional to the intensity of the*
nt.'

n these principles Ohm founded the celebrated law which bears his
, that—

e intensity of the current is equal to the electromotive force divided
e resistance.

hich is expressed by the simple formula

$$I = \frac{E}{R},$$

e I is the intensity of the current, E the electromotive force, and R
esistance.

ii. tance of a conductor depends on three elements: its *conductivity,* h is a constant, determined for each conductor; its *section*; and its *length*. The resistance is obviously inversely proportional to the conductivity, that is, the less the conducting power the greater the resistance. This has been experimentally shown, and it has also been proved that *the resistance is inversely as the section and directly as the length of a conductor.* If then κ is the conductivity, ω the section, and λ the length of a conductor, we have

$$R = \frac{\lambda}{\kappa\omega} \text{ and } I = \frac{E}{\frac{\lambda}{\kappa\omega}} = \frac{\kappa\omega E}{\lambda},$$

that is, *the intensity of a* *rsely proportional to the length of the conductor and directl* *o its section and conductivity.*

iii. In a voltaic battery different elements, the intensity of the current is equal to e electromotive forces of all the elements divided by the s esistances. Usually, however, a battery is composed of el ame kind, each having the same electromotive force and t nce.

In an ordinary element there ntially two resistances to be considered: 1. That offered by the liquid conductor between the two plates, which is frequently called the *internal* or *essential resistance*; and, 2. That offered by the interpolar conductor which connects the two plates outside the liquid; this conductor may consist either wholly of metal, or may be partly of metal and partly of liquids to be decomposed: it is the *external* or *non-essential resistance.* Calling the former R and the latter r, Ohm's formula becomes

$$I = \frac{E}{R + r}.$$

iv. If any number, n, of similar elements are joined together, there is n times the electromotive force, but at the same time n times the internal resistance, and the formula becomes $\frac{nE}{nR + r}$. If the resistance in the interpolar, r, is very small, which is the case, for instance, when it is a short thick copper wire, it may be neglected in comparison with the internal resistance, and then we have

$$I = \frac{nE}{nR} = \frac{E}{R};$$

that is, a battery consisting of several elements produces in this case no greater effect than a single element.

v. If, however, the external resistance is very great, as when the current has to produce the electric light, or to work a telegraphic circuit, then advantage is gained by using a larger number of elements; for then in the formula

$$I = \frac{nE}{nR + r},$$

if r is so great as compared with nR, the latter may be neglected, and the expression becomes

$$I = \frac{nE}{r};$$

that is, that the intensity within certain limits is proportional to the number of elements.

In a thermo-electric pile, which consists of very short metallic conductors, the internal resistance R is so small that it may be neglected, and the intensity is inversely as the length of the connecting wire.

vi. If the plates of an element be made m times as large, there is no increase in the electromotive force, for this depends on the nature of the metals and of the liquid, but the resistance is m times as small, for the section is m times larger; the expression becomes then

$$I = \frac{E}{\frac{R}{m} + r} = \frac{E}{R + mr}$$

Hence, an increase in the size of the plate, or, what is the same thing, a decrease in the internal resistance, does not increase the intensity to an indefinite extent; for ultimately the resistance of the element R vanishes in comparison with the resistance r, and the intensity always approximates to the value $I = \frac{E}{r}$.

vii. Ohm's law enables us to arrange a battery so as to obtain the greatest effect in any given case. For instance, with a battery of six elements there are the following four ways of arranging them: 1. In a single series (fig. 610), in which the zinc Z of one element is united with the copper C of the second; the zinc of this with the copper of the third, and so on; 2. Arranged in a system of three double elements, each element being formed by joining two of the former (fig. 611); 3. In a system of two elements, each of which consists of three of the original elements joined, so as to form one of triple the surface (fig. 612); 4. Lastly, of one large element, all the zincs and all the coppers being joined, so as to form a larger pair of six times the surface (fig. 613).

With a series of twelve elements there may be six different combinations, and so on for a larger number.

Now let us suppose that in the particular case of a battery of six elements the internal resistance R of each element is 3, and the external resistance $r = 12$. Then in the first case where there are six elements we have the value,

$$I = \frac{6E}{6R + r} = \frac{6E}{6 \times 3 + 12} = \frac{6E}{30}.$$

If they were united so as to form three elements, each of double the surface, as the second case (fig. 611), the electromotive force then would be, the electromotive force in each element; there would also be a resistance

R in each element, but this would only be half as great, for the sectio the plate is now double; hence the intensity in this case would be

$$I' = \frac{3E}{\frac{3R}{2} + r} = \frac{3E}{\frac{9}{2} + 12} = \frac{6E}{33};$$

hence this change would lessen the intensity.

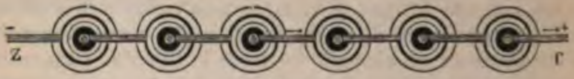


Fig. 610.

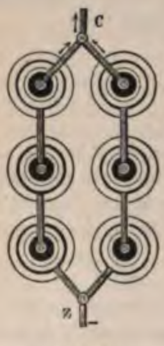


Fig. 611.

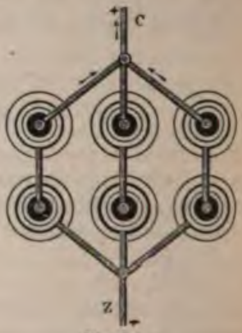


Fig. 612.

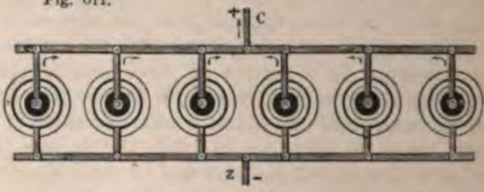


Fig. 613.

If with the same elements the resistance in the connecting wire wer only $r = 2$, we should have the values in the two cases respectively—

$$I = \frac{6 \times E}{6 \times 3 + 2} = \frac{6E}{20},$$

$$\text{and } I' = \frac{3E}{\frac{3R}{2} + r} = \frac{6E}{9 + 4} = \frac{6E}{13}.$$

The result in the latter case is, therefore, more favourable. If the resist-ance r were 9, the intensity would be the same in both cases. Hence, by altering the size of the plates or the arrangement, favourable or unfavourable results are obtained according to the relation between R and r.

can be shown that *in any given combination the maximum effect is ined when the total resistance in the elements is equal to the resistance le interpolar.* Suppose that in a given case n elements are arranged s to form a battery of s couples, each consisting of t cells, then $n = st$. ioting the resistance of a single element by r, the total resistance of battery thus arranged is $\frac{rs}{t}$. Now, according to the above law, the kimum effect is obtained when $\frac{rs}{t} = l$, where l is the resistance of the rpolar. But $t = \frac{n}{s}$, hence $\frac{rs^2}{n} = l$, or $s = \sqrt{\frac{ln}{r}}$.

f in a given case we have 8 elements, each offering a resistance 15, an interpolar with the resistance 40, we get $s = 4{\cdot}3$. But this is impossible arrangement, for it is not a whole number, and the rest whole number must be taken. This is 4, and it will be found on king a calculation analogous to that above, that when arranged as to form 4 elements, each of double surface, the greatest effect is ained.

CHAPTER III.

EFFECTS OF THE CURRENT.

5o. **Physiological actions.**—Under this name are included the cts produced by the battery-current on living organisms or tissues.

Vhen the electrodes of a strong battery are held in the two hands a ent shock is felt, especially if the hands are moistened with acidulated er, which increases the conductivity. The violence of the shock omes greater in proportion to the number of elements used, and with rger number—as 200 Bunsen's cells—is even dangerous.

he power of contracting upon the application of a voltaic current ns to be a very general property of protoplasm—the physical basis of l animal and vegetable life; if, for example, a current of moderate ngth be passed through such a simple form of protoplasm as an œba, it immediately withdraws its processes, ceases its changes of n, and contracts into a rounded ball—soon, however, resuming its vity upon the cessation of the current. Essentially similar effects of the rent have been observed in the protoplasm of young vegetable cells.

f a frog's fresh muscle (which will retain its vitality for a considerable e after removal from the body of the animal) be introduced into a anic circuit, no apparent effect will be observed during the steady sage of the current, but every opening or closure of the circuit will se a muscular contraction, as will also any sudden and considerable ration in its intensity. By very rapidly interrupting the current, the cle can be thrown into a state of uninterrupted contraction, or physiocal *tetanus*, each new contraction occurring before the previous one passed off. Other things being equal, the amount of shortening exhibited by the muscle increases, up to a certain limit, with the intensity of the current. These phenomena entirely disappear with the life of the muscle; hence the experiments are somewhat more difficult with warm-blooded animals, the vitality of whose muscles, after exposure or removal from the body, is maintained with more difficulty; but the results of careful experiment are exactly the same here as in the case of the frog.

The influence of an electric current upon living nerves is very remarkable; as a general rule, it may be stated that its effect is to throw the nerve into a state of activity, whatever its special function may be; thus, if the nerve be one going to a muscle, the latter will be caused to contract; if it be one of common sensation, pain will be produced; if one of special sense, the sensation of a flash of light, or of a taste, etc., will be produced, according to the nerve irritated. These effects do not manifest themselves during the even passage of the current, but only when the circuit is either opened or closed, or both. Of course, the continuity of the nerve with the organ where its activity manifests itself must be maintained intact. The changes set up by the current in the different nerve trunks are probably similar, the various sensations, etc. produced depending on the different terminal organs with which the nerves are connected.

761. **Electrotonus.**—In a living nerve, as will be stated more fully in Chapter X., certain parts of the surface are electropositive to certain other parts, so that if a pair of electrodes connected with a galvanometer be applied to these two points, a current will be indicated; if now another part of the nerve be interposed in a galvanic circuit, it will be found that, if this extraneous current be passing in the same direction as the proper nerve current, the latter is increased, and *vice versâ*; and this, although it has previously been demonstrated experimentally that none of the battery current escapes down the nerve, so as to exert any influence of its own on the galvanometer. This alteration of its natural electromotive condition, produced through the whole of a nerve by the passage of a constant current through part of it, is known as the *electrotonic state*; it is most intense near the extraneous, or, as it is called, the *exciting current*. It continues as long as the latter is passing, and is attended with important changes in the *excitability* of the nerve, or, in other words, the readiness with which the nerve is thrown into a state of functional activity by any stimulus applied to it. Pflüger, who has investigated these changes, has named the part of the nerve through which the exciting current is passing the *intrapolar region*; the condition of the nerve close to the positive pole is called *anelectrotonus*; that near the negative pole, *kathelectrotonus*. The excitability of the nerve is diminished in the anelectrotonic region, so that with a motor nerve, for example, a stronger stimulus than before would need to be applied at this part, in order to obtain a muscular contraction; in the kathelectrotonic region, on the contrary, the excitability of the nerve is heightened. Moreover, with an exciting current of moderate strength the power of the nerve to conduct a stimulus is lowered in the anelectrotonic region, and increased in the kathelectrotonic; with strong currents it is said to be diminished in both.

These facts have to be taken into account in the scientific application of galvanism to medical purposes; if, for instance, it is wished to diminish the excitability of the sensory nerves of any part of the body, the current should be passed in such a direction as to throw the nerves of that part into a state of anelectrotonus—and similarly in other cases.

If a powerful electric current be passed through the body of a recently killed animal, violent movements are produced, as the muscles ordinarily retain their vitality for a considerable time after general systemic death; by this means, also, life has been re-established in animals which were apparently dead—a properly applied current stimulating the respiratory muscles to contract.

762. **Thermal effects.**—When a voltaic current is passed through a metallic wire the same effects are produced as by the discharge of an electric battery; the wire becomes heated, and even incandescent if it is very short and thin. With a powerful battery all metals are melted, even iridium and platinum, the least fusible of metals. Carbon is the only body which hitherto has not been fused by it. M. Despretz, however, with a battery composed of 600 Bunsen's elements joined in six series (759), has raised rods of very pure carbon to such a temperature that they were softened and could be welded together, indicating an incipient fusion.

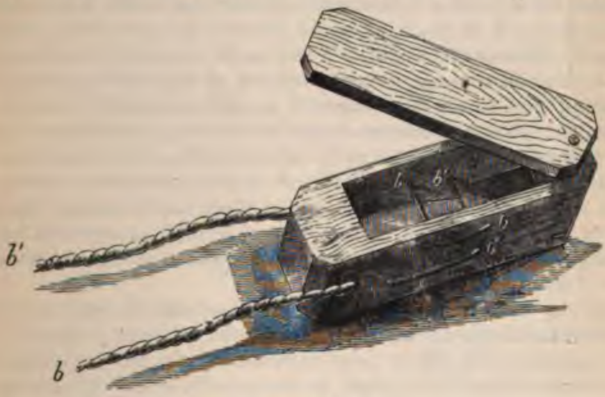


Fig. 614.

A battery of 30 to 40 Bunsen's elements is sufficient to melt and volatilise fine wires of lead, tin, zinc, copper, gold, silver, iron, and even platinum, with differently coloured sparks. Iron and platinum burn with a brilliant white light; lead with a purple light; the light of tin and of gold is bluish white; the light of zinc is a mixture of white and gold; finally, copper and silver give a green light.

The thermal effects of the voltaic current are used for firing mines for military purposes and for blasting operations. The following arrangement devised by Colonel Schaw, is adopted in the English service. Fig. 614

represents a small wooden box provided with a lid. Two moderately stout copper wires, insulated by being covered with gutta-percha, are deprived of this coating at the ends, which are then passed through and through the box in the manner represented in the figure. The distance between them is $\frac{3}{8}$ of an inch, and a very fine platinum wire (one weighing 1·92 grains to the yard is the regulation size) is soldered across. The object of arranging the wires in this manner is that they shall not be in contact, and the strain which they exert may be spent on the box, and not on the platinum wire joining them, which, being very thin, would be broken by a very slight pull. The box is then filled with fine-grained powder, and the lid tied down. The wires of the fuse are then carefully joined to the long conducting wires, which lead to the battery ; these should be of copper, and as thick as is convenient, so as to offer very little resistance : No. 16 gauge copper wire is a suitable size. The fuse is then introduced into the charge to be fired : if it is for a submarine explosion, the powder is contained in a canister, the neck of which, after the introduction of the fuse, is carefully fastened by means of cement. When contact is made with the battery, which is effected through the intervention of mercury cups, the current traversing the platinum wire renders it incandescent, which fires the fuse ; and thus the ignition is communicated to the charge in which it is placed.

The thermal effect depends more on the size than on the number of the plates of a battery, for the resistance in the connecting wires is small. An iron wire may be melted by a single Wollaston's element, the zinc of which is 8 inches by 6. Hare's battery (740) has received its name *deflagrator* on account of its greater heating effect produced by the great surface of its plates.

When any circuit is closed, a definite amount of heat is produced throughout the entire circuit ; and the amount of heat produced in any particular part of the circuit is greater, the greater the proportion which the resistance of this part bears to the entire circuit. Hence in firing mines the wire to be heated should be of as small section and of as small conductivity as practicable. These conditions are well satisfied by platinum, which has over iron the advantage of being less brittle and of not being liable to rust. Platinum too has a low specific heat, and is thus raised to a higher temperature by the same amount of heat than a wire of greater specific heat.

On the other hand, the conducting wires should present as small a resistance as possible, a condition satisfied by a stout copper wire ; and again, as the heating effect of any circuit is proportional to the square of the intensity, and as this is directly as the electromotive force, and inversely as the resistance, a battery with a high electromotive force, and small resistance, such as Grove's or Bunsen's, should be selected.

By means of a heated platinum wire, parts of the body may be safely cauterised which could not be got at by a red-hot iron ; the removal of tumours may be effected by drawing a loop of platinum round their base, which is then gradually pulled together. It has been observed that when the temperature of the wire is about 600° C., the combustion of the tissues is so complete that there is no hæmorrhage ; while at 1500° the action of the wire is like that of a sharp knife.

763. **Laws of heating effects. Galvano-thermometer.**—Although the thermal effects are most obvious in the case of thin wires, they are not limited to them ; with thicker wires they may be perceived by means of delicate thermometric arrangements, by which also the laws of the heating effect may be investigated.

Such an arrangement is called a *galvano-thermometer.* It consists essentially of a glass vessel containing alcohol, in which is a delicate thermometer ; the wire to be investigated is fitted to two platinum wires fused in the well-ground stopper of the vessel. The current is passed through the platinum wires, and its intensity measured by means of a tangent compass interposed in the circuit. By observing the increase of temperature in the thermometer in a given time, and knowing the weight of the alcohol, the mass of the wire, the specific heat, and the calorimetric values (419) of the vessel, and of the thermometer, compared with alcohol, the thermal effect which is produced by the current in a given time can be calculated.

By apparatus of this kind the laws of the thermal effects have been investigated by Lenz, Joule, and Becquerel. They are as follows :

I. *The heat disengaged in a given time is directly proportional to the square of the intensity of the current, and to the resistance of the wire.*

II. *Whatever be the length of the wire, provided its diameter remains the same, and that the same quantity of electricity passes, the increase of temperature is the same in all parts of the wire.*

III. *For the same quantity of electricity, the increase of temperature in different parts of the wire is inversely as the fourth power of the diameter.*

If the current passes through a chain of platinum and silver wire of equal sizes, the platinum becomes more heated than the silver from its greater resistance; and with a suitable current the platinum may become incandescent while the silver remains dark. This experiment was devised by Children. If a long thin platinum wire be raised to dull redness by passing a voltaic current through it, and if part of it be cooled down by ice, the resistance of the cooled part is diminished, the intensity of the current increases, and the rest of the wire becomes brighter than before.

If, on the contrary, a part of the feebly incandescent wire be heated by a spirit-lamp, the resistance of the heated part increases, for the effect is the same as that of introducing fresh resistance, the intensity of the current diminishes, and the wire ceases to be incandescent in the non-heated part.

The cooling by the surrounding medium exercises an important influence on the phenomenon of ignition. A round wire is more heated by the same current than the same wire which has been beaten out flat; for the latter with the same section offers a greater surface to the cooling medium than the others. For the same reason, when a wire is stretched in a glass tube on which two brass caps are fitted air-tight, and the wire is raised to dull incandescence by the passage of a current, the incandescence is more vivid when the air has been pumped out of the tube, because it now simply loses heat by radiation, and not by communication to the surrounding medium.

Similarly, a current which will melt a wire in air will only raise it to dull redness in ether, and in oil or in water will not heat it to redness at all, for the liquids conduct heat away more readily than air does.

From the above laws it follows that the heating effect is the same in a wire whatever be its length, provided the current is constant; but it must be remembered that by increasing the length of the wire we increase the resistance, and consequently diminish the intensity of the current; further, in a long wire there is a greater surface, and hence more heat is lost by radiation and by conduction.

764. **Relation of heating effect to work of a battery.**—In every closed circuit chemical action is continually going on; in ordinary circuits, the most common action is the solution of zinc in sulphuric acid, which may be regarded as an oxidation of the zinc to form oxide of zinc, and a combination of this oxide of zinc with sulphuric acid to form water and zinc sulphate. It is a true combustion of zinc, and this combustion serves to maintain all the actions which the circuit can produce, just as all the work which a steam-engine can effect has its origin in the combustion of fuel (440).

By independent experiments it has been found that, when a given weight of zinc is dissolved in sulphuric acid, a certain definite measurable *quantity* of heat is produced, which, as in all cases of chemical action, is the same, whatever be the rapidity with which the solution is effected. If this solution takes place while the zinc is associated with another metal so as to form a voltaic couple, the rapidity of the solution will be altered, and the whole circuit will become heated—the liquid, the plates, the containing vessel as well as the connecting wire. But although the distribution of the heat is thus altered, its quantity is not. If the values of all the several heating effects in the various parts of the circuit be determined, it will still be found that this sum is exactly equivalent to that produced by the solution of a certain weight of zinc.

If the couple be made to do external mechanical work the case is different. Joule has made the following remarkable experiment. A small zinc and copper couple were arranged in a calorimeter and the amount of heat determined while the couple was closed for a certain length of time by a short thick wire. The couple still contained in the calorimeter was next connected with a small electromagnetic engine (796), by which a weight was raised. It was thus found that the heat produced in the calorimeter in a given time—while therefore a certain amount of zinc was dissolved—was less while the couple was doing work than when it was not; and the amount of this diminution was the exact thermal equivalent of the work performed in raising the weight.

765. **Luminous effects.**—In closing a voltaic battery a spark is obtained at the point of contact, which is frequently of great brilliance. A similar spark is also perceived on breaking contact. These luminous effects are obtained when the battery is sufficiently powerful, by bringing the two electrodes very nearly in contact; a succession of bright sparks

springs sometimes across the interval, which follow each other with such rapidity as to produce a continuous light. With eight or ten of Grove's elements brilliant luminous sparks are obtained by connecting one terminal of the battery with a file, and moving its point along the teeth of another file connected with the other terminal.

The most beautiful effect of the electric light is obtained when, with the terminals of the battery, two pencils of charcoal are connected in the manner represented in fig. 615. The charcoal *b* is fixed, while the charcoal *a* can be raised and lowered by means of a rack and pinion motion, *c*. The two charcoals being placed in contact, the current passes, and their ends soon become incandescent. If they are then removed to a distance of about the tenth of an inch, according to the intensity of the current, a luminous arc extends between the two points, which has an exceedingly brilliant lustre, and is called the *voltaic arc.*

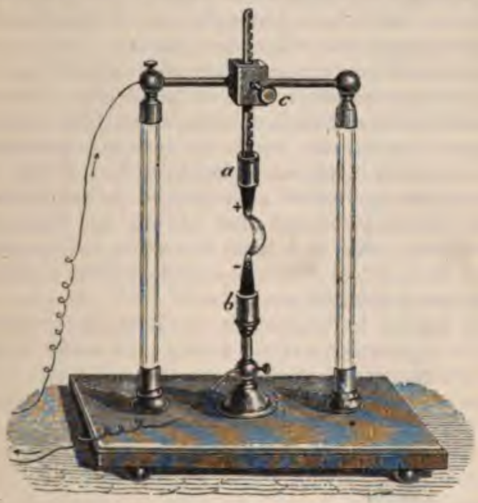


Fig. 615.

The length of this arc varies with the force of the current. In air it may exceed 2 inches with a battery of 600 elements, arranged in six series of 100 each, provided the positive pole is uppermost, as represented in the figure; if it is undermost, the arc is about one-third shorter. In vacuo the distance of the charcoal may be greater than in air; in fact, as the electricity meets with no resistance, it springs between the two charcoals, even before they are in contact. The voltaic arc can also be produced in liquids, but it is then much shorter, and its brilliancy is greatly diminished.

The voltaic arc has the property that it is attracted when a magnet is presented to it; a consequence of the action of magnets on currents.

Some physicists have considered the voltaic arc as formed of a very rapid su[illegible]n of bright sparks. Its colour and shape depend on the nature o[illegible]onductors between which it is formed, and hence it is probable [illegible]t is due to the incandescent particles of the conductor, which are volatilised and transported in the direction of the current—that is, from the positive to the negative pole. The more easily the electrodes are disintegrated by the current, the greater is the distance at which the electrodes can be placed. Charcoal, which is a very friable substance, is one of the bodies which gives the largest luminous arc.

Recent researches by Edlund have shown that this disintegration of the terminals by the voltaic arc gives rise to an electromotive force opposed in direction to th[illegible] current.

Davy first made the [illegible] electric light, in 1801, by means of a battery of 2,000 [illegible]ches square. He used charcoal points made of light wood [illegible]ich had been heated to redness, and immersed in a mercu[illegible] mercury, penetrating into the pores of the charcoal, incre[illegible]ductivity. When any substance was introduced into the vo[illegible]luced by this battery, it became incandescent; platinum m[illegible]ax in the flame of a candle; sapphire, magnesia, lime, [illegible]fractory substances were fused. Fragments of diamond, of cha[illegible] of graphite rapidly disappeared without undergoing any previous fusion.

As charcoal rapidly burns in air, it was necessary to operate in vacuo, and hence the experiment was for a long time made by fitting the two points in an electric egg, like that represented in fig. 576. At present the electrodes are made of gas graphite, a modification of charcoal deposited

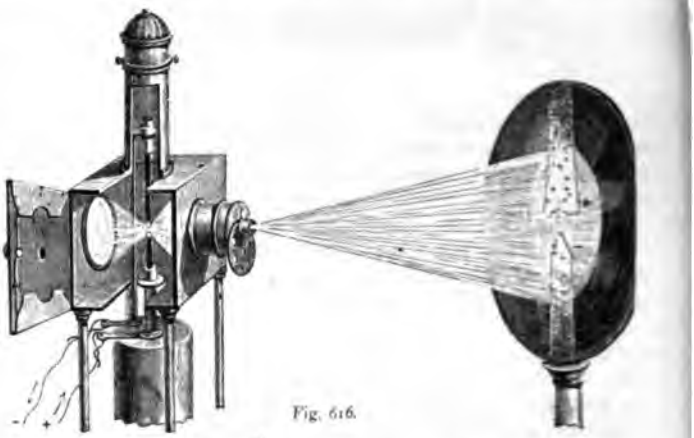


Fig. 616.

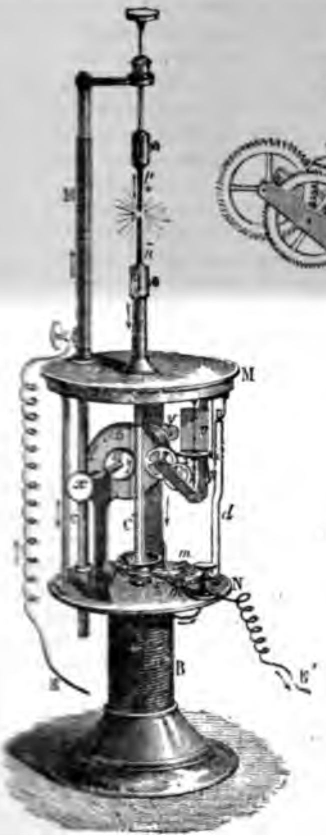
in gas retorts; this is hard and compact, and only burns slowly in air: hence it is unnecessary to operate in vacuo. When the experiment is made in vacuo, there is no combustion, but the charcoal wears away at the positive pole, while it is somewhat increased on the negative po indicating that there is a transport of solid matter from the positive to the negative pole.

766. **Foucault's experiment.**—This consists in projecting on a screen the image of the charcoal points produced in the camera obscura at the moment at which the electric light is formed (fig. 616). By means of this experiment, which is made by the photo-electric microscope already described (fig. 455), the two charcoals can be readily distinguished, and the positive charcoal is seen to become somewhat hollow and diminish, while the other increases. The globules represented on the two charcoals arise from the fusion of a small quantity of silica contained in the charcoal. When the current begins to pass, the negative charcoal first becomes luminous, but the light of the positive charcoal is the brightest; as it also wears away the most rapidly, it ought to be rather the larger.

767. **Regulator of the electric light.**—When the electric light is to be used for illumination, it must be as continuous as other modes of lighting. For this purpose, not only must the current be constant, but the distance of the charcoals must not alter, which necessitates the use of some arrangement for bringing them nearer together in proportion as they wear away. One of the best modes of effecting this is by an apparatus invented by M. Duboscq.

In this regulator the two charcoals are moveable, but with unequal velocities, which are virtually proportional to their waste. The motion is transmitted by a drum placed on the axis, *xy* (fig. 617). This turns in the direction of the arrows two wheels, *a* and *b*, the diameters of which are as 1 : 2, and which respectively transmit their motion to two rack-works, C′ and C. C lowers the positive charcoal, *p*, by means of a rod sliding in the tube, H, while the other C′ raises the negative charcoal, *n*, half as rapidly. By means of the milled head *y* the drum can be wound up, and at the same time the positive charcoal moved by the hand; the milled head *x* moves the negative charcoal also by the hand, and independently of the first. For this purpose the axis, *xy*, consists of two parts pressing against each other with some force, so that, holding the milled head *x* between the fingers, the other, *y*, may be moved, and by holding the latter the former can be moved. But the friction is sufficient when the drum works to move the two wheels *a* and *b* and the two rack-works.

The two charcoals being placed in contact, the current of a powerful battery of 40 to 50 elements reaches the apparatus by means of the wires, E and E′. The current rising in H descends by the positive charcoal, then by the negative charcoal, and reaches the apparatus, but without passing into the rackwork, C, or into the part on the right of the plate, N; these pieces being insulated by ivory discs placed at their lower part. The current ultimately reaches the bobbin B, which forms the foot of the regulator, and passes into the wire, E′. Inside the bobbin is a bar of soft iron, which is magnetised as long as the current passes in the bobbin, and demagnetised when it does not pass, and this temporary magnet is the regulator. For this purpose it acts attractively on an armature of soft iron, A, open in the centre so as to allow the rackwork C′ to pass, and fixed at the end of a lever, which works on two points, *mm*, transmits a slight oscillation to a rod, *d*, which, by means of a catc stops the wheel *z*, as is seen on a larger scale in figure 618. By endless screw, and a series of toothed wheels, the stop is transmitted the drum, and the rackwork being fixed, the same is the case with carbons. This is what takes place so long as the magnetisation in



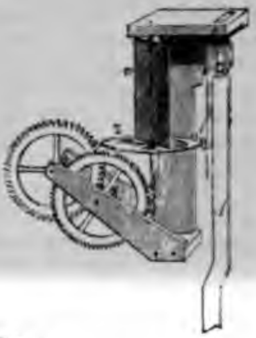


Fig. 618.

Fig. 617.

[illegible] enough to keep down the armature, A; but in propo the carbons wear away, the current becomes feebler, though the vo [illegible] continues, so that ultimately the attraction of the magnet no lo [illegible] a spring, *r*, which continually tends to raise the arma [illegible] the piece *d* disengages the stop *i*, the drum works, the carbons come nearer; they do not, however, touch, because ty of the current gains the upper hand, the armature A is attracted, carbons remain fixed. As their distance only varies within very limits, a regular and con- light is obtained with this tus until the carbons are sed.

neans of this regulator, M. cq illuminates the photo- pparatus represented in fig. y which all the optical ex- nts may be performed for solar light was formerly ary.

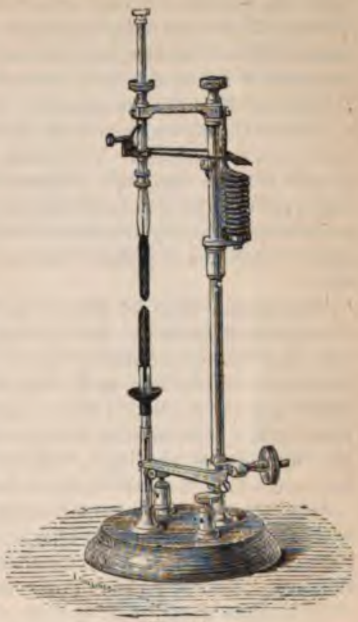


Fig. 619.

Browning's regulator.—h simpler apparatus, repre- in fig. 619, has been devised John Browning. It has the dvantage of being less costly he other lamps, and also of ing a smaller number of ele- to work it. The current the lamp by a wire attached inding screw on the base of trument, passing up the pillar small electromagnet to the pillar along the top of the ntal bar, down the left-hand rough the two carbons, and by a wire attached to a g screw on the left hand. A tube holding the upper carbon slides up and down a tube at the end of the cross-piece, and would by n weight rest on the lower carbon, but the electromagnet is pro- with a keeper, to which is attached a rest that encircles the tube and grasps it. When the electromagnet works and attracts eper, the rest tightens and thereby prevents the descent of the . When the keeper is not attracted the rest loosens, and the holder descends.

en the two carbons are at rest, on making contact with a battery rrent traverses both carbons and no light is produced. But if the carbon be raised ever so little, a brilliant light is emitted. When mp is thus once set to work, the rod attached to the upper carbon e let go, and the magnet will afterwards keep the lamp at work. hen some of the carbon is consumed, and the interval between the too great for the current to pass, the magnet loses some of its power, eper loosens its hold on the carbon, and this descends by its own t. When they are sufficiently near, but before they are in contact, rrent is re-established; the magnet again draws on the keeper, and eper again checks the descent of the carbon, and so forth. Thus

the points are retained at the right distances apart, and the light is c
tinuous and brilliant.

769. **Properties and intensity of the electric light.**—The elec
light has similar chemical properties to solar light ; it effects the com
nation of chlorine and hydrogen, acts chemically on chloride of silv
and applied to photography gives fine impressions remarkable for t
warmth of its tones ; it is, however, inapplicable for taking portraits,
it fatigues the sight too greatly.

Passed through a prism, the electric light, like the sun, is decompos
and gives a spectrum. Wollaston, and more especially Fraunhofer, ha
found that the spectrum of the electric light differs from that of oth
lights and of the sun-light by the presence of several very bright lin
as has been already stated. Wheatstone was the first to observe that
using electrodes of different metals, the spectrum and the lines are mo
fied.

Masson has recently studied the electric light in great detail, and h
experimented upon the light of the electric machine, that of the volta
arc, and that of Ruhmkorff's coil. He has found the same colours i
the electric spectrum as in the solar spectrum, but traversed by ve
brilliant luminous bands of the same shade as that of the colour in whic
they occur. The number and position of these bands do not depend o
the intensity of the light, but, as we have seen, upon the substanc
between which the voltaic arc is formed.

With carbon the lines are remarkable for their number and brilliancy
with zinc the spectrum is characterised by a very marked apple-gre
tint ; silver produces a very intense green ; with lead a violet tint pr
dominates, and so on with other metals.

Bunsen, in experimenting with 48 couples, and removing the charcoal
to a distance of a quarter of an inch, has found that the intensity of th
electric light is equal to that of 572 candles.

Fizeau and Foucault have compared the chemical effects of the sol
and the electric lights, by investigating their action on iodized silv
plates. Representing the intensity of the sun-light at midday at 100
these physicists found that that of 46 Bunsen's elements was 235, whi
that of 80 elements was only 238. It follows that the intensity do
not increase to any material extent with the number of the couples; bu
experiment shows that it increases considerably with their surface. Fo
with a battery of 46 elements, each consisting of 3 elements, with the
zinc and copper respectively united so as to form one element of tripl
surface (759), the intensity was 385, the battery working for an hour
that is to say, more than a third of the intensity of the solar light.

Despretz observes that too great precautions cannot be taken agains
the effects of the electric light when they attain a certain intensity. Th
light of 100 couples, he says, may produce very painful affections of th
eyes. With 600, a single moment's exposure to the light is sufficient t
produce very violent headaches and pains in the eye, and the whole fram
is affected as by a powerful sunstroke.

Mr. Way has obtained a very bright light by passing the electric urrent along a stream of mercury. The light is produced by the incandescence of the mercury vapour ; it has a somewhat flickering character, nd a greenish tinge.

Attempts have been made to apply the electric light to the illumination f rooms, and even of streets ; but partly the cost, and partly the difficulty f producing with it a uniform illumination, inasmuch as the shadows are hrown into too sharp relief, have hitherto been great obstacles to its use. et it is advantageously applied in special cases, such as the photo-electric nicroscope, illuminations in theatres, etc.

770. **Mechanical effects of the battery.**—Under this head may be ncluded the motion of solids and liquids effected by the current. An xample of the former is found in the voltaic arc, in which there is a assage of the molecules of carbon from the positive to the negative pole 765).

If, in a slightly inclined glass tube, a thread of liquid be contained etween two platinum wires fused in the glass, and if a current of electricity be passed through the liquid by means of these electrodes, then, if he positive electricity moves upwards, the liquid will be carried along rith it—it will become somewhat raised. The ascent is proportional to he intensity of the current and to the section of the tube. The phenomenon is met with in alcohol and in turpentine, but in a contrary direction ; he liquid rising in the direction of the negative electricity.

A similar phenomenon, known as *electrical endosmose*, is observed in he following experiment, due to Porret. Having divided a glass vessel nto two compartments by a porous diaphragm consisting of bladder, he oured water into the two compartments to the same height, and immersed two electrodes of platinum in connection with a battery of 80 ements. As the water became decomposed, part of the liquid was rried in the direction of the current, through the diaphragm, from the ositive to the negative compartment, where the level rose above that in e other compartment. A solution of blue vitriol is best for these periments, because then the disturbing influence of the disengagement gas at the negative electrode is avoided.

The converse of these phenomena is observed when a liquid is forced rough a diaphragm by mechanical means ; electrical currents are oduced, if on both sides the diaphragm, metal electrodes of the same aterial are immersed in the liquid in conducting communication with ch other. Such currents, which were discovered by Quincke, are lled *diaphragm currents.*

According to Wertheim, the elasticity of metallic wires is diminished the current, and not by the heat alone, but by the electricity ; he s also found that the cohesion is diminished by the passage of a rrent.

To the mechanical effects of the current may be assigned the sounds oduced in soft iron when submitted to the magnetic action of a discontinuous current—a phenomenon which will be subsequently described.

771. **Chemical effects.**—These are among the most impo all the actions, either of the simple or compound circuit. decomposition effected battery was that of obtained in 1800 by and Nicholson by m a voltaic pile. W rapidly decomposed b Bunsen's cells; the a (fig. 620) is very co for the purpose. It of a glass vessel fix wooden base. In the of the vessel two electrodes, *p* and *n*, a communicating by m copper wires with the binding screws. The vessel is filled with which some sulphuric acid has been added to increase its conduct pure water is a very imperfect conductor; two glass tubes fil water are inverted over the electrodes, and on interposing the a in the circuit of a battery decomposition is rapidly set up, bubbles rise from the surface of each pole. The volume of gas at the negative pole is about double that at the positive, and mination the former gas is found to be hydrogen and the la oxygen. This experiment accordingly gives at once the qualita quantitative analysis of water. The oxygen thus obtained peculiar and penetrating odour observed when an electrical ma worked (729), and which is due to ozone. The water containe same time some peroxide of hydrogen, in producing which som is consumed. Moreover oxygen is somewhat more soluble in wa hydrogen. Owing to these causes the volume of oxygen is less t required by the composition of water, which is two volumes of h to one of oxygen. Hence voltametric measurements are mo when the hydrogen alone is considered, and when this is liberat surface of a small electrode.

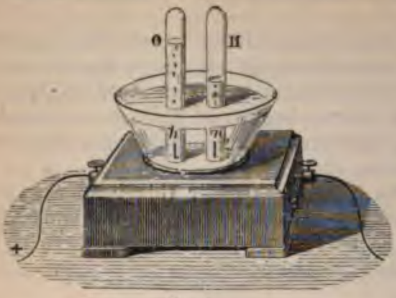


Fig. 620.

772. **Electrolysis.**—To those substances which, like water, solved into their elements by the voltaic current, the term *electr* been applied by Faraday, to whom the principal discoveries subject and the nomenclature are due. *Electrolysis* is the decom by the voltaic battery; the positive electrode was by Faraday c *anode*, and the negative electrode the *kathode*. The products of position are *iones*; *katione*, that which appears of the kathode; an that which appears at the anode.

By means of the battery, the compound nature of several su which had previously been considered as elements has been det By means of a battery of 250 couples, Davy, shortly after the d of the decomposition of water, succeeded in decomposing the potass and soda, and proved that they were the oxides of the unknown metals potassium and sodium. The decomposition of potass may be demonstrated with the aid of the battery of 4 to 6 elements in the following manner; a small cavity is made in a piece of solid caustic potass, which is moistened, and a drop of mercury placed in it (fig. 621). The potass is placed on a piece of platinum connected with the positive pole of the battery. The mercury is then touched with the negative pole. When the current passes, the potass is decomposed, oxygen is liberated at the positive pole, while the potassium liberated at the negative pole amalgamates with the mercury. On distilling this amalgam out of contact with air, the mercury passes off, leaving the potassium.

The decomposition of binary compounds—that is, bodies containing two elements—is quite analogous to that of water and of potass; one of he elements goes to the positive, and the other to the negative pole. The bodies separated at the positive pole are called *electronegative* elements, because at the moment of separation they are considered to be harged with negative electricity, while those separated at the negative ole are called *electropositive* elements. One and the same body may be lectronegative or electropositive, according to the body with which it is ssociated. For instance, sulphur is electronegative towards hydrogen, ut is electropositive towards oxygen. The various elements may be rranged in such a series that any one in combination is electronegative o any following, but electropositive towards all preceding ones. This is alled the *electrochemical series*, and begins with oxygen as the most lectronegative element, terminating with potassium as the most electro-ositive.

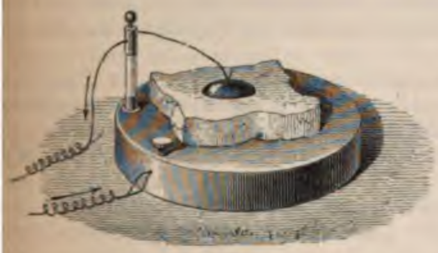


Fig. 621.

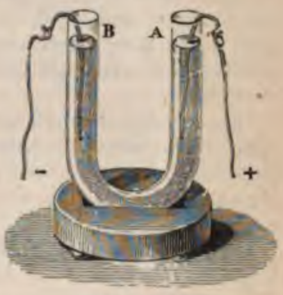


Fig. 622.

The decomposition of hydrochloric acid into its constituents, chloride nd hydrogen, may be shown by means of the apparatus represented in g. 622. Carbon electrodes must, however, be substituted for those of latinum, which is attacked by the liberated chlorine; a quantity of salt lso must be added to the hydrochloric acid, in order to diminish the olubility of the liberated chlorine. The decomposition of iodide of po-ssium may be demonstrated by means of a single element. For this urpose a piece of bibulous paper is soaked with a solution of starch, to which iodide of potassium is added. On touching this paper with the electrodes, a blue spot is produced at the positive pole, due to the action of the liberated iodine on the starch.

773. **Decomposition of salts.**—Ternary salts in solution are decomposed by the battery, and then present effects varying with the chemical affinities, and the intensity of the current. In all cases the acid, or the body which is chemically equivalent to it, is electronegative in its action towards the other constituent. The decomposition of salts may be readily shown by means of the bent tube represented in fig. 622. This is nearly filled with a saturated solution of a salt, say sulphate of sodium, coloured with tincture of violets. The platinum electrodes of a battery of four Bunsen's elements are then placed in the two legs of the tube. After a few minutes the liquid in the positive leg, A, becomes of a red, and that in the negative leg, B, of a green colour, showing that the salt has been resolved into acid which has passed to the positive, and into a base which has gone to the negative pole, for these are the effects which a free acid and a free base respectively produce on tincture of violets.

In a solution of sulphate of copper, free acid and oxygen gas appear at the positive electrode, and metallic copper is deposited at the negative electrode. In like manner, with nitrate of silver, metallic silver is deposited on the negative, while free acid and oxygen appear at the positive electrode.

This decomposition of salts was formerly explained by saying that *the acid was liberated at the positive electrode and the base at the negative.* Thus sulphate of potassium, K_2OSO_3, was considered to be resolved into sulphuric acid, SO_3, and potash, K_2O. This view regarded salts composed of three elements as different in their constitution from binary or haloid salts. Their electrolytic deportment has led to a mode of regarding the constitution of salts which brings all classes of them under one category. In sulphate of potassium, for instance, the electropositive element is potassium, while the electronegative element is a complex of sulphur and oxygen, which is regarded as a single group, SO_4, and to which the name ***oxy-sulphion*** may be assigned. The formula of sulphate of potassium would thus be K_2SO_4, and its decomposition would be quite analogous to that of chloride of potassium, KCl, chloride of lead, $PbCl_2$, iodide of potassium, KI. The electronegative group SO_4 corresponds to a molecule of chlorine or iodine. In the decomposition of sulphate of potassium the potassium liberated at the negative pole decomposes water, forming potash and liberating hydrogen. In like manner the electronegative constituent SO_4, which cannot exist in the free state, decomposes into oxygen gas, which is liberated, and into anhydrous sulphuric acid, SO_3, which immediately combines with water to form ordinary sulphuric acid, H_2SO_4. In fact, where the action of the battery is strong these gases are liberated at the corresponding poles; in other cases they combine in the liquid itself, reproducing water. The constitution of sulphate of copper, $CuSO_4$, and of nitrate of silver, $AgNO_3$, and their decomposition, will be readily understood from these examples.

4. **Transmissions effected by the current.**—In chemical decomtions effected by the battery there is not merely a separation of the ents, but a passage of the one to the positive and of the other to the tive electrode. This phenomenon has been demonstrated by Davy neans of several experiments, of which the two following are exles :—

He placed solution of sulphate of sodium in two capsules connected thread of asbestos moistened with the same solution, and immersed ositive electrode in one of the capsules, and the negative electrode e other. The salt was decomposed, and at the expiration of some all the sulphuric acid was found in the first capsule, and the soda in econd.

Having taken three glasses, A, B, and C (fig. 623), he poured into the solution of sulphate of sodium, into the second dilute syrup of ts, and into the third pure water, and connected them by moistened ds of asbestos. The current was then passed in the direction from A. The sulphate in the vessel A was decomposed, and in the course ne there was nothing but soda in this glass, which formed the negaend, while all the acid had been transported to the glass C, which positive. If, on the contrary, the currents passed from A to C, the was found in C, while all the acid remained in A ; but in both cases emarkable phenomenon seen that the syrup of ts in B neither became nor green by the passage e acid or base through ass, a phenomenon the nation of which is based the hypothesis enund in the following parah.

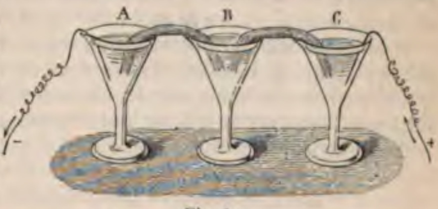


Fig. 623.

5. **Grotthüss's hypothesis.**—Grotthüss has given the following exation of the chemical decompositions effected by the battery. pting the hypothesis that in every binary compound, or body which as such, one of the elements is electropositive, and the other electroitive, he assumes that, under the influence of the contrary electricities e electrodes, there is effected in the liquid in which they are imed a series of successive decompositions and recompositions from pole to the other. Hence only the elements of the inal molecules which do recombine, and remainree appear at the eleces. Water, for instance, med of one atom of oxygen and two atoms of hydrogen, the first eing electronegative, and the second electropositive. Hence when quid is traversed by a sufficiently powerful current, the molecule *a* ntact with the positive pole arranges itself as shown in fig. 624, that

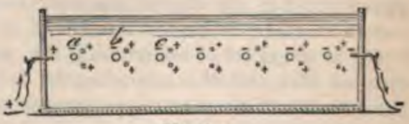


Fig. 624.

is, the oxygen is attracted and the hydrogen repelled. The oxygen of this molecule is then given off at the positive electrode, the liberated hydrogen immediately unites with the oxygen of the molecule *b*, the hydrogen of this with the oxygen of the molecule *c*, and so on, to the negative electrode, where the last atoms of hydrogen become free and appear on the poles. The same theory applies to the metallic oxides, to the acids and salts, and explains why in the experiment mentioned in the preceding paragraph the syrup of violets in the vessel B becomes neither red nor green. The reason why, in the fundamental experiment, the hydrogen is given off at the negative pole when the circuit is closed will be readily understood from a consideration of this hypothesis.

776. **Laws of electrolysis.**—The laws of electrolysis were discovered by Faraday; the most important of them are as follows:—

I. *Electrolysis cannot take place unless the electrolyte is a conductor.* Hence ice is not decomposed by the battery, because it is a bad conductor. Other bodies, such as oxide of lead, chloride of silver, etc., are only electrolysed in a fused state—that is, when they can conduct the current.

II. *The energy of the electrolytic action of the current is the same in all its parts.*

III. *The same quantity of electricity—that is, the same electric current—decomposes chemically equivalent quantities of all the bodies which it traverses*; from which it follows, *that the weights of elements separated in these electrolytes are to each other as their chemical equivalents.*

If an apparatus for decomposing water (fig. 621) and various U-shaped tubes containing respectively fused oxide of lead and chloride of tin are interposed in the same voltaic current, which must be sufficiently powerful, these substances will be decomposed; the electronegative elements will be separated at the positive and the electropositive at the negative poles. The quantitives of substances liberated are in a certain definite relation. Thus for every 18 parts of water decomposed in the voltameter there will be liberated 2 parts of hydrogen, 207 parts of lead, and 117 of tin at the respective negative electrodes, and 16 parts of oxygen, and 71 (or $2 \times 35{\cdot}5$) parts of chlorine at the corresponding positive electrode. Now these numbers are exactly as the equivalents (not as the atomic weights) of the bodies.

It will further be found that in each of the cells of the battery 65 parts by weight of zinc have been dissolved, for every two parts by weight of hydrogen liberated; that is, that for every equivalent of a substance decomposed in the circuit one equivalent of zinc is dissolved. This is the case whatever be the number of cells. An increase in the number only has the effect of overcoming the great resistance which many electrolytes offer, and of accelerating the decomposition. It does not increase the quantity of the electrolyte decomposed. If in any of the cells more than 65 parts of zinc are dissolved for every two parts of hydrogen liberated, this arises from a disadvantageous succeeding local action; and the more perfect the battery, the more nearly does it approach this ratio.

IV. It follows from the above law, that *the quantity of a body decom-*

osed in a given time is proportional to the intensity of the current. On his is founded the use of Faraday's *voltameter*, in which the intensity of current is ascertained from the quantity of water which it decomposes n a given time. It consists of a glass vessel, in which two platinum lectrodes are fixed. In the neck of a vessel a bent delivery tube is itted, and the mixed gases are collected in a graduated cylinder, so that heir volume can be determined, which, reduced to a constant temperaure and pressure, is a measure of their quantity.

The use of this voltameter appears simple and convenient; and hence some physicists have proposed *as unit of the intensity of the current, that intensity which in one minute yields a cubic centimeter of mixed gas reduced to the temperature* 0° *and the pressure* 760 *mm.* Yet, for reasons mentioned before (771), the measurements should be based on the volume of hydrogen liberated.

The *silver voltameter* is an instrument for measuring the intensity of the current. A solution of nitrate of silver of known strength is placed in a platinum dish which is connected with the negative pole; in this solution is placed the positive pole, which consists of a rod of silver wrapped round with muslin. The silver which separates at the negative pole is washed, dried, and weighed; and the weight thus roduced in a given time is a measure for the intensity of the current. The silver particles which become detached from the positive pole are etained in the muslin.

The current from the electrical machine, which is of very high intensity, s capable of traversing any electrolyte, but the quantity which it can ecompose is extremely small as compared even with the smallest voltaic pparatus, and it must be concluded that the quantity developed by the ictional machine is very small as compared with that developed by hemical action.

It has been calculated by Weber, that if the quantity of positive elecicity required to decompose a grain of water were accumulated on a oud at a distance of 3,000 feet from the earth's surface, it would exert n attractive force upon the earth of upwards of 1,500 tons.

777. **Comparison between the Tangent Compass and the Voltaeter.**—There are several objections to the use of the voltameter. In e first place, it does not indicate the intensity at any given moment, for order to obtain measurable quantities of gas the current must be ntinued for some time. Again, the voltameter gives no indications of e changes which take place in this time, but only the mean intensity. offers also great resistance, and can thus only be used in the case of rong currents; for such currents either do not decompose water, or ly yield quantities too small for accurate measurement. In addition this, the indications of the voltameter depend not only on the intensity the current, but on the acidity of the water, and on the distance and ze of the electrodes.

The magnetic measurements are preferable to the chemical ones. Not nly are they more delicate and offer less resistance, but they give the tensity at any moment. On the other hand, indications furnished by the tangent compass hold only for one special instrument. They vary with the diameter of the ring and the number of turns; moreover, one and the same instrument will give different indications on different places, seeing that the force of the earth's magnetism varies from one place to another.

The indications of the two instruments may, however, be readily compared with one another. For this purpose the voltameter and the tangent compass are *simultaneously* inserted in the circuit of a battery, and the deflection of the needle and the amount of gas liberated in a given time are noted. In one special set of experiments the following results were obtained :—

Number of Elements.	Deflection.	Gas liberated in three minutes.
12	28·5°	125cc.
8	24·8	106
6	22·0	92·5
3	13·75	56·0
2	6·9	23·7

If we divide the tangents of the angle into the corresponding volume of gas liberated in *one* minute, we should obtain a constant magnitude which represents how much gas is developed in a minute by a current which could produce on the tangent compass the deflection 45°, for tang. 45° = 1. Making this calculation with the above observations, we obtain a set of closely agreeing numbers the mean of which is 76·5. The gas was measured under a pressure of 737 mm. and at a temperature of 31·5°, and therefore under normal conditions (306) its volume would be 70 cubic centimeters. That is to say, this is the volume of gas which corresponds to a deflection of 45°.

Hence in chemical measure the strength I of a current which produces in *this* particular tangent compass a deflection of ϕ° is

$$I = 70 \text{ tang. } \phi.$$

For instance, supposing a current produced in this tangent compass a deflection of 54°, this current, if it passed through a voltameter, would liberate in a minute $70 \times \text{tang. } 54 = 70 \times 1{\cdot}376 = 96{\cdot}32$ cubic centimeters of gas.

If once the *reduction factor* for a tangent compass has been determined, the strength of any current may be readily calculated in chemical measure by a simple reading of the angle of deflection. This reduction factor of course only holds for one special instrument, and for experiments on the same place, seeing that the force of the earth's magnetism varies in different places.

The indications of the sine-compass may be compared with those of the galvanometer in a similar manner.

778. **Polarisation.**—When the platinum electrodes, which have been used in decomposing water, are disconnected from the battery, and con-

ted with a galvanometer, the existence of a current is indicated which s the opposite direction to that which had previously passed. This enomenon is explained by the fact that oxygen has been condensed on surface of the positive plate, and hydrogen on the surface of the gative plate, analogous to what has been already seen in the case of non-constant batteries (741). The effect of this is to produce two ferent electromotors, which produce a current opposed in direction to original one, and which, therefore, must weaken it. As the two ctrodes thus become the poles of a new current, they are said to be *arised*, and the current is called a *polarisation-current.*

)n this principle batteries may be constructed of pieces of metal of the ne kind—for instance, platinum—which otherwise give no current. A ce of moistened cloth is interposed between each pair, and each end his system is connected with the poles of a battery. After some time apparatus has received a charge, and if separated from the battery itself produce all the effects of a voltaic battery. Such batteries are led *secondary* batteries. Their action depends on an alteration of the face of the metal produced by the electric current; the constituents of liquid with which the cloth is moistened having become accumulated the opposite plates of the circuit.

\ dry pile which has become inactive may be used as a secondary tery. When a current is passed through it, in a direction contrary to t which the active battery yields, it then regains its activity.

Co this class belongs *Planté's* secondary battery, which consists of concentric cylinders of sheet lead, which do not touch, and are nersed in dilute acid. They are charged by being placed in contact h a battery of two or three cells, and there is an arrangement by which y can be detached from the battery and their current utilised. They ve in a certain sense to store up and transform the power of the nary battery, and produce effects of great intensity.

79. **Grove's gas battery.**—On the property, which metals have, of densing gases on their surfaces, Grove has constructed his *gas battery.* its simplest form it consists of two glass tubes, in each of which is ed a platinum electrode, provided on the outside with binding screws. ese electrodes are made more efficient by being covered with finely ided platinum. One of the tubes is partially filled with hydrogen, the other partially with oxygen, and they are inverted over dilute huric acid, so that half the platinum is in the liquid and half in gas. connecting the electrodes with a galvanometer, the existence of a rent is indicated, whose direction in the connecting wire is from the inum in oxygen to that in hydrogen; so that the latter is negative ards the former. As the current passes through water this is decomed; oxygen is separated at the positive plate, and hydrogen at the er. These gases unite with the gases condensed on their surface, so t the volume of gas in the tubes gradually diminishes, but in the ratio ne volume of oxygen to two volumes of hydrogen. These elements be formed into a battery by joining the dissimilar plates with one ther just as they are joined in an ordinary battery. One element of

a silver plate, and the silver is touched in the middle piece of zinc, there are formed around the point of copper rings alternately dark and light. These are *No* They may be obtained in beautiful iridescent colou process: A solution of oxide of lead in potash is finely powdered litharge in a solution of potash. In mersed a polished plate of silver or of German silver with the positive electrode of a battery of eight Buns the negative pole is connected a fine platinum wire fu only its point projects; and this is placed in the liqui from the plate. Around this point binoxide of lead plate in very thin concentric layers, the thickness of the middle. They show the same series of colours a rings in transmitted light. The binoxide of lead secondary decomposition; by the passage of the cu lead is decomposed into lead, which is deposited at th oxygen which is liberated at the positive; and this ox some oxide of lead to form binoxide, which is depos pole as the decomposition proceeds.

The effects are also well seen if a solution of su placed on a silver plate, which is touched with a zi which is in the solution; for then a current is form and the liquid.

782. **Arbor Saturni, or lead tree.** **Arbor** solution of a salt, is immersed a metal which is more metal of the salt, the latter is precipitated by the fo mersed metal is substituted equivalent for equivalent

flask, being closed, is left to itself. At the expiration of a few days brilliant laminæ of metallic lead are deposited on the brass wires, closely resembling vegetation, from which the old alchemical name is derived. For the same reason the name *arbor Dianæ* has been given to the metallic deposit produced in a similar manner by mercury in a solution of nitrate of silver.

ELECTROMETALLURGY.

783. **Electrometallurgy.**—The decomposition of salts by the battery has received a most important application in *electrometallurgy*, or *galvanoplastics*, by which is meant thé art of precipitating metals from their solutions by the slow action of a galvanic current. The art was discovered independently by Spencer in England, and by Jacobi in Petersburg.

In order to reproduce a medal or any other object by this process, a hollow cast must first be made, on which is deposited the metallic layer, which reproduces the medal in relief. If the medal is of metal, the simplest way to form the cast is to use a fusible alloy (314), which may consist of 5 parts of lead, 8 of bismuth, and 3 of tin. Some of the melted alloy is poured into a shallow box, and just as it begins to solidify the medal is placed horizontally on it in a fixed position. When the alloy has become cool, a slight shock is sufficient to detach the medal. A copper wire is then bound round the edge of the mould, by which it can be connected with the negative electrode of the battery, and then the edge and he back are covered with a thin non-conducting layer of wax, so that the deposit is only formed on the mould itself.

In order to take a copper cast, a bath is filled with saturated solution of sulphate of copper, and two copper rods, B and D, stretched across fig. 625)—one connected with the negative and the other with the positive pole of a Grove's, or preferably, from its greater constancy, a Daniell's element. From the rod connected with the negative pole is uspended the mould *m*, and from the other a plate of copper, C. The urrent being thus closed, the sulphate of copper is decomposed, acid is berated at the positive pole, while copper is deposited at the negative

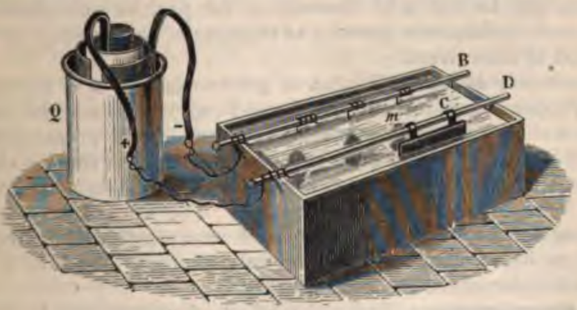


Fig. 625.

pole, on the mould suspended from the rod, B, to which indeed severa moulds may be attached. At the expiration of 48 hours the mould i covered with a non-adherent, solid, resisting layer of copper. In orde completely to avoid adherence, the mould ought previously to immersio to be brushed with a fine brush passed lightly over a fatty body, c rapidly passed through a smoky flame, so as to form a very slight deposi of solid matter.

If the cast to be reproduced is of plaster, an alloy cannot be used. I must first be immersed in a bath of melted stearine, and withdraw quickly; when withdrawn it dries almost immediately, which arises fro a penetration of stearine into the pores of the plaster. When cooled i is coated with graphite, or black lead, which is rubbed with a brush; band of cartridge paper is then affixed round the edge, and some plaste or melted stearine is poured upon it; on cooling this gives a hollow ca of the original medal. This is prevented from adhering to the plaster b the layer of graphite; it is removed and covered with graphite in ord to make it conduct. The mould thus prepared is suspended, as in th previous case, from the negative pole of the battery.

Gutta-percha also gives very sharp moulds. The object, of which th cast is to be taken, is coated with a layer of graphite to prevent adherenc and then a quantity of gutta-percha having been placed in hot water un it is quite soft, is pressed against the object to be copied. On detachi the gutta-percha a very faithful hollow cast of the object is obtain This cast is covered with graphite in order to make it conduct; bei connected with the negative pole, it is then suspended in a concentrat solution of sulphate of copper, and in about 48 hours a copper copy of original object is obtained.

The copper plate suspended from the positive pole serves a double p pose: it not only closes the current, but it keeps the solution in a stat concentration, for the acid liberated at the positive pole dissolves copper, and reproduces a quantity of sulphate of copper equal to that composed by the current.

An extremely useful application of galvanoplastics is to the reprod tion of copper plates, for clichés of wood-engravings, and the like. prepare a cliché of a wood-engraving, a matrix is first prepared eithe papier-mâché or in plaster of Paris. An impression of this is cast in t metal, and the side to be printed is coated with a thin layer of copper, which its durability is greatly increased. The same matrix serves producing a large number of casts. With what great accuracy the cop reproduces impressions appears from galvanoplastic copies of daguer types, which are of the greatest accuracy.

784. **Electrogilding.**—The old method of gilding was by means mercury. It was effected by an amalgam of gold and mercury, wh was applied on the metal to be gilt. The objects thus covered w heated in a furnace, the mercury volatilised, and the gold remained a very thin layer on the objects. The same process was used for sil ing; but they were expensive and unhealthy methods, and have t been entirely replaced by electrogilding and electrosilvering. Elec

ilding only differs from the process described in the previous paragraph n that the layer is thinner and adheres more firmly. Brugnatelli, a upil of Volta, appears to have been the first, in 1803, to observe that a ody could be gilded by means of the battery and an alkaline solution of old; but M. de la Rive was the first who really used the battery in ilding. The methods both of gilding and silvering owe their present igh state of perfection principally to the improvements of Elkington, uolz, and other physicists.

The pieces to be gilt have to undergo three processes before gilding.

The first consists in heating them so as to remove the fatty matter hich has adhered to them in previous processes.

As the objects to be gilt are usually of copper, and their surface during e operation of heating becomes covered with a layer of suboxide or of rotoxide of copper, this is removed by the second operation. For this rpose the objects, while still hot, are immersed in very dilute nitric acid, here they remain until the oxide is removed. They are then rubbed ith a hard brush, washed in distilled water, and dried in gently heated wdust.

To remove all spots they must undergo the third process, which con-ists in rapidly immersing them in ordinary nitric acid, and then in a ixture of nitric acid, bay salt, and soot.

When thus prepared the objects are attached to the negative pole of a attery, consisting of three or four Bunsen's or Daniell's elements. They re then immersed in a bath of gold, as previously described. They remain n the bath for a time which depends on the thickness of the desired de-osit. There is great difference in the composition of the baths. That ost in use consists of 1 grain of chloride of gold, 10 grains of cyanide of otassium, dissolved in 200 grains of water. In order to keep the bath in a tate of concentration, a piece of gold is suspended from the positive lectrode, which dissolves in proportion as the gold dissolved in the bath s deposited on the objects attached to the negative pole.

The method which has just been described can not only be used for ilding copper, but also for silver, bronze, brass, German silver, etc. But ther metals, such as iron, steel, zinc, tin, and lead, are very difficult to ild well. To obtain a good coating, they must first be covered with a ayer of copper by means of the battery and a bath of sulphate of copper; he copper with which they are coated is then gilded, as in the previous ase.

785. **Electrosilvering.**—What has been said about gilding applies xactly to the process of electrosilvering. The difference is in the com-osition of the bath, which consists of two parts of cyanide of silver, and wo parts of cyanide of potassium dissolved in 250 parts of water. To the ositive electrode is suspended a plate of silver, which prevents the bath rom becoming poorer: the pieces to be silvered, which must be well leaned, are attached to the negative pole.

CHAPTER IV.

ELECTRODYNAMICS. ATTRACTION AND REPULSION OF CURRENTS BY CURRENTS.

786. **Electrodynamics.**—Under *electrodynamics* is understood the laws of electricity in a state of motion, or the action of electric currents upon each other and upon magnets, while *electrostatics* deals with the laws of electricity in a state of rest.

The action of one electrical currrent upon another was first investigated by Ampère, shortly after the discovery of Oersted's celebrated fundamental experiment (754). All the phenomena, even the most complicated, follow from two simple laws, just as the theorems of geometry from the axioms. These laws are—

I. *Two currents which are parallel, and in the same direction, attract one another.*

II. *Two currents parallel, but in contrary directions, repel one another.*

In order to demonstrate these laws, the circuit which the current traverses must consist of two parts, one fixed and the other moveable.

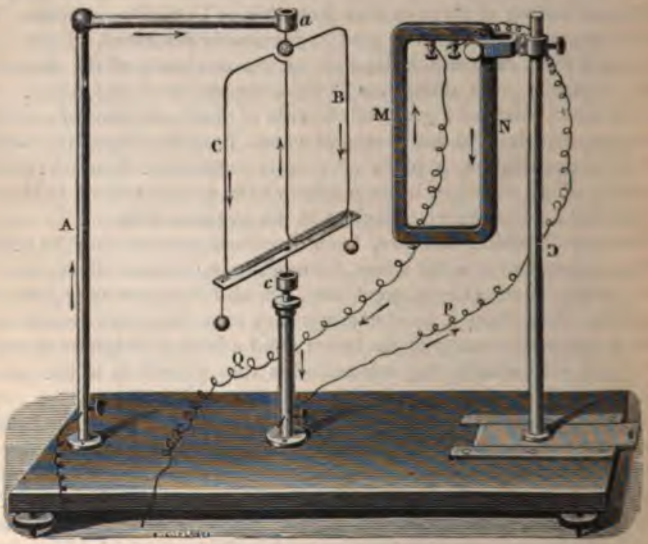


Fig. 626.

This is effected by the following apparatus (fig. 626), which is a modified and improved form of one originally devised by Ampère.

It consists of two brass columns, A and D, between which is a shorter

. The column D is provided with a multiplier of 20 turns, MN (fig.), which greatly increases the sensitiveness of the instrument. This be adjusted at any height and in any position by means of a universal w clamp (see figs. 626, 628–631).

he short column is hollow, and in its interior glides a brass tube ter- ating in a mercury cup, *c*, which can be raised or lowered. On the umn A is another mercury cup represented in section at fig. 627 in its ural size. In the bottom is a capillary aperture through which passes point of a sewing needle fixed to a small copper ball. This point ex- ds as far as the mercury, and turns freely in the hole. The moveable t of the circuit consists of a copper wire proceeding from the small let, and turning in the direction of the arrows from the cup *a* to the cup The two lower branches are fixed to a thin strip of wood, and the whole tem is balanced by two copper balls sus- ded to the ends.

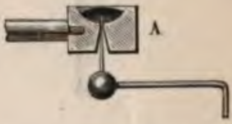


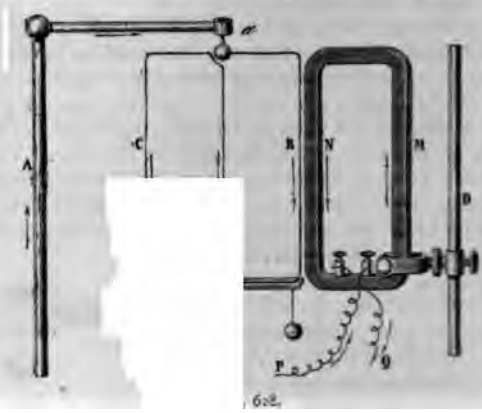
Fig. 627.

he details being known, the current of a nsen's battery of 4 or 5 cells ascending by column A (fig. 626) to the cup *a*, traverses circuit BC, reaches the cup *c*, descends central column, and thence passes by a e, P, to the multiplier MN, from whence eturns to the battery by the wire Q. Now if, before the current passes, moveable circuit has been arranged in the plane of the multiplier, the es B and M opposite each other, when the current passes the side B epelled, which demonstrates the second law; for in the branches B d M the currents, as indicated by the arrows, are proceeding in opposite ections.

To demonstrate the first law the experiment is arranged as in figure 628— t is, the multiplier is reversed; the current is then in the same direction th in the multiplier and in the moveable part; and when the latter is noved out of the plane of the multiplier, so long as the current passes ends to return to it, proving that there is attraction between the two rts.

787. **Roget's vibrating spiral.**—The attraction of parallel currents y also be shown by an experiment known as that of *Roget's vibrating iral.* A copper wire about 0·7 mm. in diameter is coiled in a spiral of out 30 coils of 25 mm. diameter. At one end it is hung vertically from inding screw, while the other just dips in a mercury cup. On passing current of a battery of 3 to 5 Grove's cells through the spiral by means the mercury cup and the binding screw, its coils traversed by parallel rrents attract one another, rise, and thus the contact with the mercury broken. The current having thus ceased, the coils no longer attract ch other, they fall by their own weight, contact with the mercury is established, and the series of phenomena are indefinitely produced. e experiment is still more striking if a magnetised rod the thickness of pencil is introduced into the interior. This will be intelligible if we nsider the action between the parallel Ampèrian currents of the agnet and of the helix.

788. **Laws of angular currents.**—I. *Two rectilinear currents, directions of which form an angle with each other, attract one an when both approach or recede from the apex of the angle.*



628.

II. *They repel one another if one approaches and the other recede the apex of the angle.*

These two laws may be demonstrated by means of the apparatus al described, replacing the moveable circuit by the circuit BC (fig. 629).

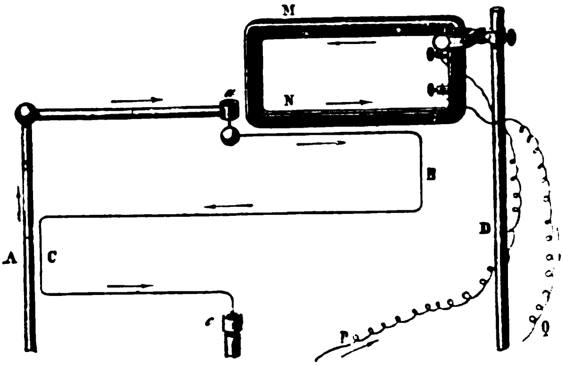


Fig. 629.

then the multiplier is placed horizontally, so that its current is in the direction as in the moveable current, if the latter is removed and the rent passes so that the direction is the same as in the moveable pa removing the latter it quickly approaches the multiplier, which verifie first law.

To prove the second law, the multiplier is turned so that the cur are in opposite directions, and then repulsion ensues (fig. 630).

a rectilinear current each element of the current repels the succeeding nd is itself repelled.

is is an important consequence of Ampère's law, and may be experi-

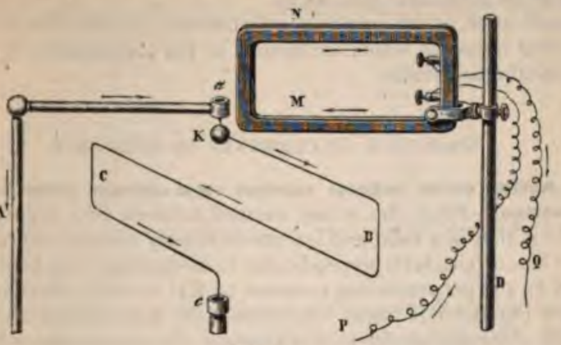


Fig. 630.

ally demonstrated by the following arrangement, which was devised araday. A U-shaped piece of copper wire, whose ends dip in two ate deep mercury cups, is suspended from one end of a delicate ce and suitably equipoised. When the mercury cups are connected the two poles of a battery, the wire rises very appreciably, and sinks to its original position when the current ceases to pass. The current s into the mercury and into the wire; but from the construction of pparatus the former is fixed, while the latter is moveable, and is acngly repelled.

. **Laws of sinuous currents.**—*The action of a sinuous current is*

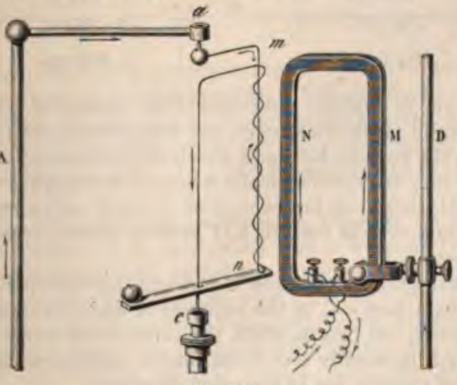


Fig. 631.

to that of a rectilinear current of the same length in projection. This iple is demonstrated by arranging the multiplier vertically and placing near it a moveable circuit of insulated wire half sinuous and half rectilinear (fig. 631). It will be seen that there is neither attraction nor repulsion, showing that the action of the sinuous portion *mn* is equalled by that of the rectilinear portion *no*.

An application of this principle will presently be met with in the apparatus called *solenoids*, which are formed of the combination of a sinuous with a rectilinear current.

DIRECTION OF CURRENTS BY CURRENTS.

790. **Action of an infinite current on a current perpendicular to its direction.**—From the action exerted between two angular currents (788) the action of a fixed and infinite rectilinear current, PQ (fig. 632), on a moveable current, KH, perpendicular to its direction, can be determined. Let OK be the perpendicular common to KH and PQ, which is null if the two lines PQ and KH meet. The current PQ flowing from Q to P in the direction of the arrows, let us first consider the case in which the current KH approaches the current QP. From the first law of angular currents (788) the portion QO of the current PQ attracts the current KH, because they both flow towards the summit of the angle formed by their directions. The portion PO, on the contrary, will repel the current KH, for here the two currents are in opposite directions at the summit of the angle. If then *mq* and *mp* stand for the two forces, one attractive and the other repulsive, which act on the current KH, and which are necessarily of the same intensity, since they are symmetrically arranged in reference to the two sides of the point O, these two forces may be resolved into a single force, *mn*, which tends to move the current KH parallel to the current QP, but in a contrary direction.

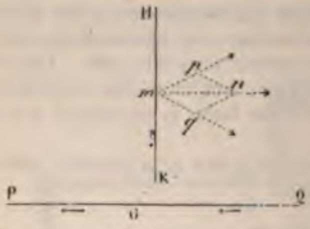


Fig. 632.

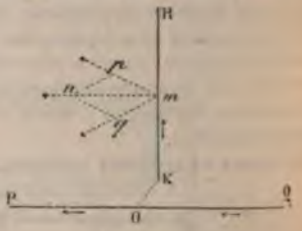


Fig. 633.

A little consideration will show that when the current KH is below the current PQ, its action will be the opposite of what it is when above.

On considering the case in which the current KH moves away from PQ (fig. 633), it will be readily seen from similar considerations that it moves parallel to this current, but in the same direction.

Hence follows this general principle. *A finite moveable current which approaches a fixed infinite current is acted on so as to move in a direction parallel and opposite to that of the fixed current; if the moveable current* *tends from the fixed current, it is acted on so as to move parallel to the current and in the same direction.*

It follows from this, that if a vertical current is moveable about an axis, XY, parallel to its direction (figs. 634 and 635), any horizontal current, PQ, will have the effect of turning the moveable current about its axis, *until the plane of the axis and of the current have become parallel* to PQ; the vertical current stopping, in reference to its axis, *on the side from which the current* PQ *comes* (fig. 634). *or on the side towards which it is directed* (fig. 635), *according as the vertical current descends or ascends*—that is, according as it approaches or moves from the horizontal axis.

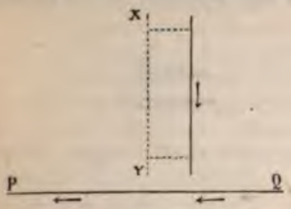


Fig 634.

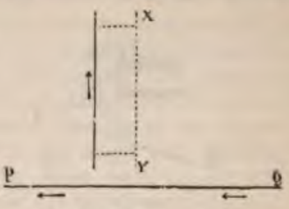


Fig. 635.

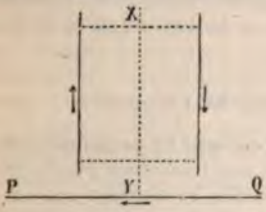


Fig. 636.

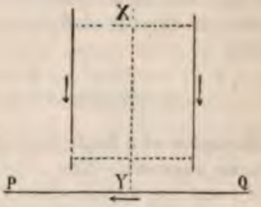


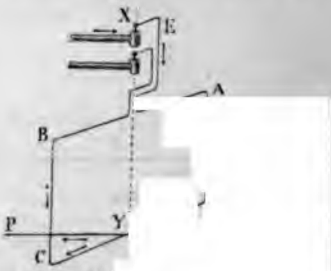
Fig. 637.

It also follows from this principle that a system of two vertical cur- ents rotating about a vertical axis (figs. 636 and 637) is directed by a orizontal current, PQ, in a plane parallel to this current, when one of the ertical currents is ascending and the other descending (fig. 636), but hat if they are both ascending or both descending (fig. 637), they are not irected.

791. **Action of an infinite rectilinear current on a rectangular r circular current.**—It is easy to see that a horizontal infinite current xercises the same directive action on a rectangular current moveable bout a vertical axis (fig. 638), as what has been above stated. For, rom the direction of the currents indicated by the arrows, the part QY cts by attraction not only on the horizontal portion YD (*law of angular urrents*), but also on the vertical portion AD (*law of perpendicular urrents*). The same action evidently takes place between the part Y and the parts CY and BC. Hence, *the fixed current* PQ *tends to irect the moveable rectangular current* ABCD *into a position parallel to*

PQ, *and* *at in the wires* CD *and* PQ *the direction of the two currents is the sa...*

This princ is readily demonstrated by placing the circuit ABCD on the apparatus with two supports (fig. 645), so that at first it makes an angle with the plane of the supports. On passing below the circuit, a somewhat powerful current in the same plane as the supports, the moveable part



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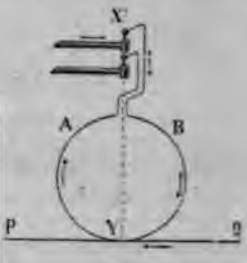


Fig. 639

passes into that plane. It i the circuit in fig. 645, which is astatic, while that of fig. 638 is not.

What has been said about the rectangular current in fig. 638 applies also to the circular current of fig. 639, and is demonstrated by the same experiments.

ROTATION OF CURRENTS BY CURRENTS.

792. **Rotation of a finite horizontal current by an infinite horizontal rectilinear current.**—The attractions and repulsions which rectangular currents exert on one another may readily be transformed into a continuous circular motion. Let OA (fig. 640) be a current moveable about the point O in a horizontal plane, and let PQ be a fixed infinite current also horizontal. As these two currents flow in the direction of the arrows,

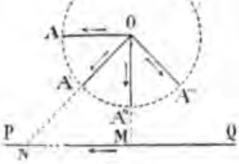


Fig. 640.

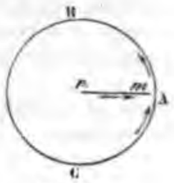


Fig. 641.

it follows that in the position OA, the moveable current is attracted by the current PQ, for they are in the same direction. Having reached the position OA', the moveable current is attracted by the part NQ of the fixed current, and repelled by the part PN. Similarly, in the position OA'' it is attracted by MQ and repelled by PM, and so on; from which follows a continuous rotatory motion in the direction AA′A″A‴. If the moveable current, instead of being directed from O towards A, were directed from A towards O, it is easy to see that the rotation would take place in the contrary direction. Hence, by the action of a fixed infinite current, PQ, the moveable current OA tends to a continuous motion *in a direction opposite that of the fixed current.*

If, both currents being horizontal, the fixed current were circular instead of being rectilinear, it is easily seen that its effect would still be to produce a continuous circular motion. For, let ABC (fig. 641) be a fixed circular current, and *mn* a rectilinear current moveable about the axis *n*, both currents being horizontal. These currents, flowing in the direction of he arrows, would attract one another in the angle *n*AC, for they both low towards the summit (788). In the angle *n*AB, on the contrary, hey repel one another, for one goes towards the summit and the other moves from it. Both effects coincide in moving the wire *mn* in the same irection ACB.

793. **Rotation of a vertical current by a horizontal circular current.** —A horizontal circular current, acting on a rectilinear vertical current, also mparts to it a continuous rotatory motion. In order to show this, the pparatus represented in fig. 642 is used.

It consists of a brass vessel, round which are rolled several coils of nsulated copper wire, through which a current passes. In the centre of e vessel is a brass support, *a*, terminated by a small cup containing ercury. In this dips a pivot supporting a copper wire, *bb*, bent at its xtremities in two vertical branches, which are soldered to a very light opper ring immersed in acidulated water contained in the vessel. The rrent of a battery entering through the wire *m*, reaches the wire A, and aving made several circuits, terminates at B, which is connected by a ire underneath with the lower part of the column *a*. Ascending in this lumn, it passes by the wires *bb* into the copper ring, into the acidulated

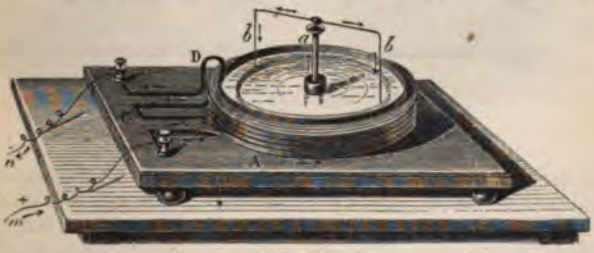


Fig. 642.

ater, and into the sides of the vessel, whence it returns to the battery the strip D. The current being thus closed, the circuit *bb* and the ng tend to turn in a direction contrary to that of the fixed current, a otion due to the action of the circular current on the current in the ver-al branches *bb*; for, as follows from the two laws of angular currents, the anch *b* on the right is attracted by the portion A of the fixed current, and the branch *b* on the left is attracted in the contrary direction by the opposite part, and these two motions coincide in giving the ring a continuous rotatory motion in the same direction. The action of the circular current on the horizontal part of the circuit *bb* would manifestly tend to turn it in the same direction; but from its distance it may evidently be neglected.

794. **Rotation of magnets by currents.**—Faraday has proved that currents impart the same rotatory motions to magnets which they do to currents. This may be shown by means of the apparatus represented in fig. 643. It consists of a large glass vessel, almost filled with mercury. In the centre of this is immersed a magnet about 8 inches in length, which projects a little above the surface of the mercury; it is loaded at its lower end with a platinum cylinder, represented at *ab* on the right of the apparatus. At the top of the magnet is a small copper cup containing mercury; the current passes into this cup by the rod C. As soon as the current ascending in the column A passes into the magnet, thence into the mercury, and emerges by the column D, the magnet begins to rotate round its own axis with a velocity depending on its magnetic power and on the intensity of the current.

This rotatory motion is readily intelligible on Ampère's theory of magnetism, which will be subsequently explained (807), according to which,

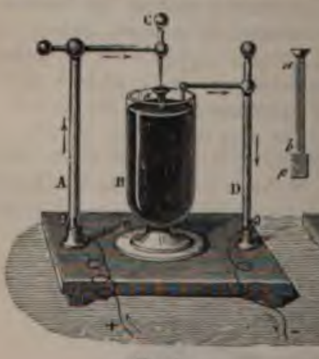


Fig. 643.

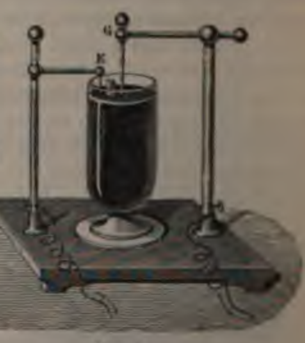


Fig. 644.

magnets are traversed on their surface by an infinity of circular currents in the same direction, in planes perpendicular to the axis of the magnet. At the moment at which the current passes from the magnet into the mercury, it is divided on the surface of the mercury into an infinity of rectilinear currents proceeding from the axis of the magnet to the circumference of the glass. Now each of these currents acts on the currents of the magnet in the same manner as, in fig. 640, the rectilinear current *mn* acts upon the circular current CAB; that is to say, that the circle CAB representing one of the currents of the magnet, there is attraction in the angle *n*AC, and repulsion in the angle *n*AB, and, consequently, rotation of the magnet round its axis. The action of the current merely affects the upper part of e magnet, and if the north pole is uppermost, as in the figure, the rota-n is from west to east. If the north pole is below, or the direction the current be altered, the rotation of the magnet is in the opposite rection.

Instead of making the magnet rotate on its axis, it may be caused to tate round a line parallel to its axis by arranging the experiment as own in fig. 644.

ACTION OF THE EARTH AND OF MAGNETS ON CURRENTS.

795. **Directive action of magnets on currents.**—Not only do currents t upon magnets, but magnets also act upon currents. In Oersted's ndamental experiment (fig. 602), the magnet being moveable while the rrent is fixed, the former is directed and sets at right angles with the rrent. If, on the contrary, the magnet is fixed and the current move-le, the latter is directed and sets across the direction of the magnet. his may be illustrated by the apparatus represented in fig. 645. This is

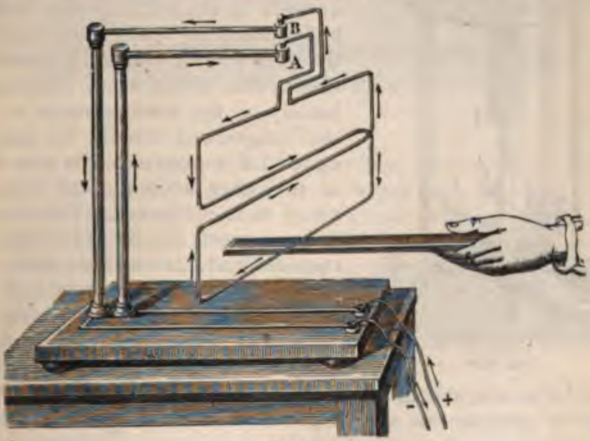


Fig. 645.

e original form of Ampère's stand, and is frequently used in experimental monstration. It needs no explanation. The circuit which the current averses is moveable, and below its lower branch a powerful bar magnet placed; the circuit immediately begins to turn, and stops after some cillations in a plane perpendicular to the axis of the magnet.

For demonstrating the action of magnets upon currents, and indeed for tablishing the fundamental laws of electrodynamics, a small apparatus, own as De la Rive's *floating battery*, is well adapted. It consists of a nall Daniell's element, contained in a glass tube attached to a cork, so at it can float freely on water. The plates are connected with minute ercury cups on the cork float; and with these can be connected either circular or rectangular wires, coils, or solenoids; and they are t traversed by a current, and can be subjected to the action eithe magnets or of currents.

796. **Rotation of currents by magnets.**—Not merely can current directed by magnets, but they may also be made to rotate, as is seen f the following experiment, devised by Faraday, fig. 646. On a base levelling screws, and resting on an i support, is a copper rod, BD. It is mounted in part of its length by a n netised bundle, AB, and at the top mercury cup. A copper circuit, balanced on a steel point, rests in cup, and the other ends of the cir which terminate in steel points, dip in annular reservoir full of mercury.

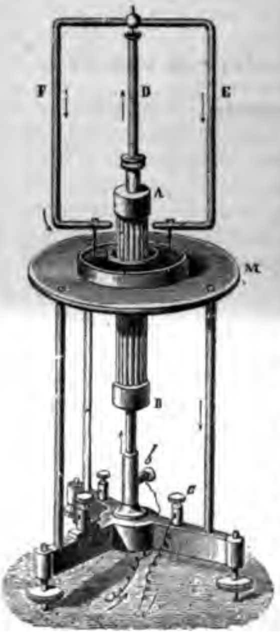


Fig. 646.

The apparatus being thus arran the current from 4 or 5 Bunsen's elem enters at the binding screw *b*; it the ascends in the rod D, redescends by two branches, reaches the mercury the steel points, whence it passes by framework, which is of copper, to battery by the binding screw *a*. If the magnetised bundle be raised, circuit EF rotates either in one direc or the other according to the pole which it is influenced. This rotatio due to currents assumed to circulate ro magnets, currents which act on the vert branches EF in the same way as circular current on the arm in fig. 642

In this experiment the magneti bundle may be replaced by a solen (802) or by an electromagnet, in which case the two binding screws in base of the apparatus on the left give entrance to the current which i traverse the solenoid or electromagnet.

797. **Electrodynamic and electromagnetic rotation of liquid** In the experiments hitherto discussed rotation is produced by causin fixed current to act upon a moveable linear current. The condition c linear current is not necessary. Fig. 647 represents an apparatus devi by M. Bertin to show the electrodynamic and electromagnetic condit of liquids. This apparatus consists of an annular earthen vessel, V that is to say, it is open in the centre so as to be traversed by a coil, This rests on a board which can be raised along two columns, E an and which are fixed by means of the screws KK. Round the vessel is a second larger coil, G, fixed on the columns SS. The vessel VV re on the lower plane. In the centre of the coil there is a bar of soft iron which makes an electromagnet.

The vessel VV contains acidulated water, and in the liquid are plunged two cylindrical copper plates, *e* and *i*, soldered to copper wires, *e′* and *i*, which convey the current of a battery of four couples through the rods E and I.

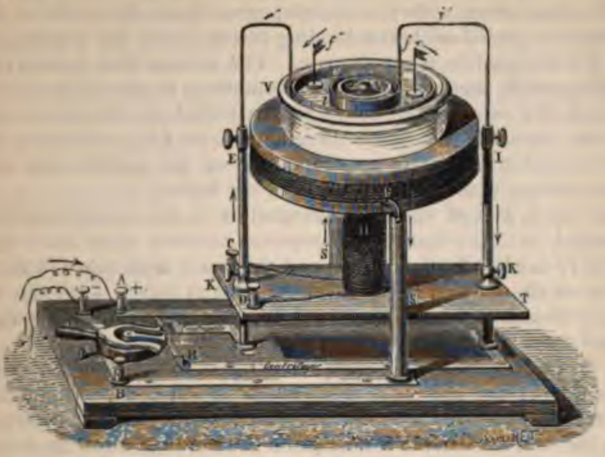


Fig. 647.

The whole system is arranged on a larger base, on the left of which is commutator represented afterwards on a larger scale (fig. 648). With e base of the columns E, I, S, and S, are connected four copper strips, ree of which lead to the commutator and the fourth to the binding rew A, which receives the wire from the positive pole.

These details being premised, the following three effects may be btained with this apparatus :—(1), the action of the coil G alone; (2), e action of the electromagnet H alone; (3), the simultaneous action of e coil and of the electromagnet.

I. Fig. 647 represents the apparatus arranged for the first effect. The urrent coming by the binding screw A attains the column S′, which ads it to the coil G, on which it is *left*—that is, in a contrary direction the hands of a watch. Then descending by the column S, it reaches e commutator, which leads it by the plate marked *centripete* to the olumn E and to the electrode *e′*. The current here traverses the quid from the circumference to the centre, attains the electrode *i*, the olumn I, and by the intervention of the plate *centrifuge* the central piece f the commutator. This transmits it finally to the negative binding crew, which leads it to the battery. The liquid then commences a *direct* rotatory motion—that is to say, in the same direction as the coil.

If the direction of the current in the liquid is *centrifugal*—that is, proceeds from the centre to the circumference—the rotation is *inverse*; that s, is in the opposite direction to that of the coil. In both cases the rotations may be shown to those at a distance by means of small flags, *f*, *f*, fixed on discs of cork which float on the liquid, and which are coated with lampblack to prevent adherence by capillary attraction between the discs and the electrodes *e* and *i*.

II. To experiment with the electromagnet alone, the positive wire of the battery is joined with the binding screw C, and the binding screws D and B are joined by a copper wire. The current first passes into the electromagnet H, then, reaching the commutator by the binding screw B, passes into the centripetal plate, whence it rises in the column E, traverses the liquid in the same direction as at first, reascends by the column I, and from thence to the centre of the commutator and the negative binding screw which leads it to the battery.

If the north pole of the electromagnet is at the same height as the glass vessel, as in the figure, the Ampèrian currents move in the opposite direction to the hands of a watch, and the floats then move in the same direction as above; and if the electromagnet is raised until the neutral line is at the same height as the vessel, the floats stop; if it is above them, the floats move again, but in the opposite direction.

III. To cause the coil and the electromagnet to act simultaneously, the positive wire of the battery is attached at C, and the binding screws D and A are connected by a conductor. Hence, after having traversed the coil H, the current arrives from D, and the binding screw A, whence it traverses exactly the same circuit as in the first experiments. The effects are the same, though more intense; the action of the coil and the electromagnet being in the same direction.

798. **Bertin's commutator.**—Commutators are apparatus by which the direction of currents may be changed at pleasure, or by which they may be opened or closed. Bertin's has the advantage of at once showing the direction of the current. It consists of a small base of hard wood on which is an ebonite plate, which, by means of the handle *m* (fig. 648), is turned about a central axis, between two stops, *c* and *c'*. On the disc are fixed two copper plates, one of which *o* is always positive, being connected by the axis and by a plate, +, with the binding screw P, which receives the positive electrode of the battery; the other, *i e*, bent in the form of a horseshoe, is connected by friction below the disc with a plate – which passes to

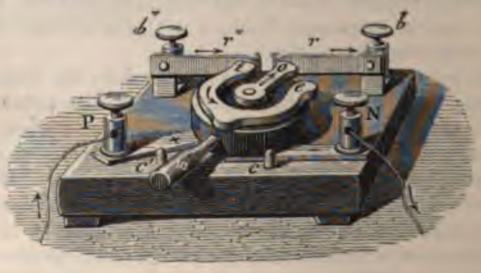


Fig. 648.

the negative electrode N. On the opposite side of the board are two binding screws, *b* and *b*, to which are adapted two elastic metal plates, *r* and *r*′.

These details being premised, the disc being turned as shown in the figure, the current coming by the binding screw P passes into the piece *o*, the plate *r* and the binding screw *b*, which by a second plate, or by a copper wire, leads it to the apparatus of fig. 647, or any other. Then, returning to the binding screw *b*, the current attains the plate *r*′, the piece *i e*, and ultimately the binding screw N, which returns it to the battery.

If the disc is turned so that the handle is half way between *c* and $c_{,}$, the pieces *o*, and *i e* being no longer in contact with the plates *r* and *r*, the current does not pass. If *m* is turned as far as *c*, the plate *o* touches $r_{,}$, the current thus passes first to *b*′ and returns by *b*; it is therefore reversed.

799. **Directive action of the earth on vertical currents.**—The earth, which exercises a directive action on magnets (642), acts also upon currents, giving them, in some cases, a fixed direction, in others a continuous rotatory motion, according as their currents are arranged in a vertical or horizontal direction.

The first of these two actions may be thus enunciated : *Every vertical current moveable about an axis parallel to itself, places itself under the directive action of the earth in a plane through this axis perpendicular to the magnetic meridian, and stops, after some oscillations, on the east of its axis of rotation when it is descending, and on the west when it is ascending.*

This may be demonstrated by means of the apparatus represented in

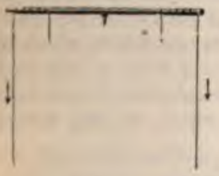


Fig. 649.

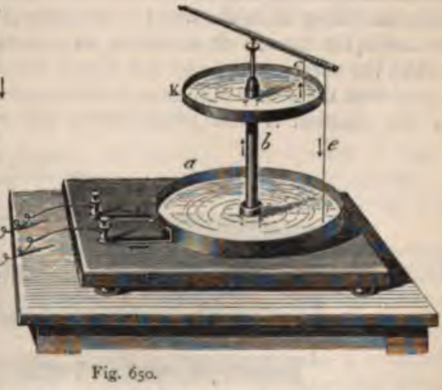


Fig. 650.

fig. 650, which consists of two brass vessels of somewhat different diameters. The larger, *a*, about 13 inches in diameter, has an aperture in the centre, through which passes a brass support, *b*, insulated from the vessel *a*, but communicating with the vessel K. This column terminates in a small cup, in which a light wooden rod rests on a pivot. At one end of this rod a fine wire is coiled, each end of which dips in acidulated water, with which the two vessels are respectively filled.

The current arriving by the wire *m* passes to a strip of copper, which is connected underneath the base of the apparatus with the bottom of the column *b*. Ascending in this column, the current reaches the vessel K, and the acidulated water which it contains; it ascends from thence in the wire *c*, redescends by the wire *e*, and traversing the acidulated water, it reaches the sides of the vessel *a*, and so back to the battery through the wire *n*.

The current being thus closed, the wire *e* moves round the column *b*, and stops to the east of it, when it descends, as is the case in the figure: but if it ascends, which is effected by transmitting the current by the wire *n*, the wire *e* stops to the west of the column *b*, in a position directly opposite to that which it assumes when it is descending.

If the rod with a single wire, in fig. 650, be replaced by one with two wires, as in fig. 651, the rod will not move, for as each wire tends to place itself on the east of the column *b*, two equal and contrary effects are produced, which counterbalance one another.

800. **Action of the earth on horizontal currents moveable about a vertical axis.**—The action of the earth on horizontal currents is not directive, but *gives them a continuous rotatory motion from the east to the west when the horizontal current moves away from the axis of rotation, and from the west to the east when it is directed towards this axis.*

This may be illustrated by means of the apparatus represented in fig. 651, which only differs from that of fig. 650 in having but one vessel. The current ascending by the column *a*, traverses the two wires *cc*, and descends by the wires *bb*, from which it regains the pile; the circuit *bccb* then begins a continuous rotation, either from the east to the west, or from the west to the east, according as in the wires *cc* the current goes from the centre, as is the case in the figure; or according as it goes towards it, which is the case when the current enters by the wire *m* instead of by *n*. But we have seen (799) that the action of the earth on the vertical wires *bb* is destroyed: hence the rotation is that produced by the action on the horizontal

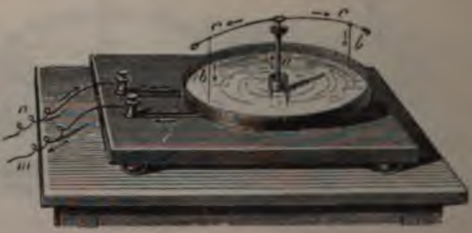


Fig. 651.

branches *cc*. This rotatory action of the terrestrial current on horizontal currents is a consequence of the rotation of a finite horizontal by an infinite horizontal current (792).

801. **Directive action of the earth on closed currents moveable about a vertical axis.**—If the current on which the earth acts is closed,

it be rectangular or circular, the result is not a continuous rotation, ective action, as in the case of vertical currents (796), in virtue of *e current places itself in a plane perpendicular to the magnetic t, so that, for an observer looking at the north, it is descending on of its axis of rotation, and ascending on the west.*

roperty, which can be shown by means of the apparatus repre- ı fig. 651, is a consequence of what has been said about horizontal ical currents. For in the ircuit BDA, the current ipper and lower parts turn in opposite direc- om the law of horizontal (800); and hence is in um, while in the lateral : current on the one side wards the east, and on r side to the west, from of vertical currents.

the directive action of h on currents, it is ne- in most experiments, to this action. This is ef- y arranging the move- uit symmetrically about of rotation, so that the directive action of the earth tends to turn opposite directions, and hence destroys them This condition is in the circuits represented in figs. 629 and 630. Hence these are called *astatic circuits.*

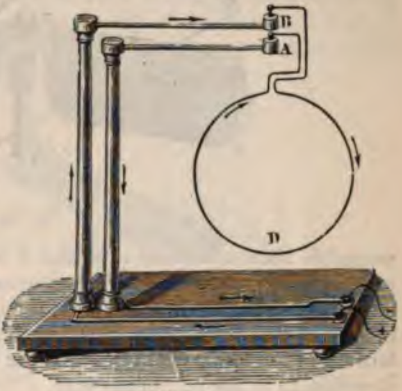


Fig. 652.

SOLENOIDS.

Structure of a solenoid.—A solenoid is a system of equal and circular currents formed of the same piece of covered copper wire, ed in the form of a helix or spiral, as represented in fig. 653. A l, however, is only complete art of the wire BC passes in ction of the axis in the interior elix. With this arrangement, ne circuit is traversed by a current, it follows from what has id about sinuous currents (789) that the action of a solenoid in a linal direction, AB, is counterbalanced by that of the rectilinear BC. This action is accordingly null in the direction of the length, *action of a solenoid in a direction perpendicular to its axis is equal to that of a series of equal parallel currents.*

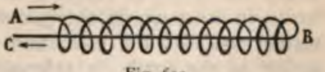


Fig. 653.

Action of currents on solenoids.—What has been said of the f fixed rectilinear currents on finite rectangular, or circular cur- 91), applies evidently to each of the circuits of a solenoid, and rectilinear current must tend to direct these circuits parallel to itself. To demonstrate this fact experimentally, a solenoid is constructed as shown in fig. 654, so that it can be suspended by two pivots in the cups *a* and *c* of the apparatus represented in fig. 626. The solenoid is then

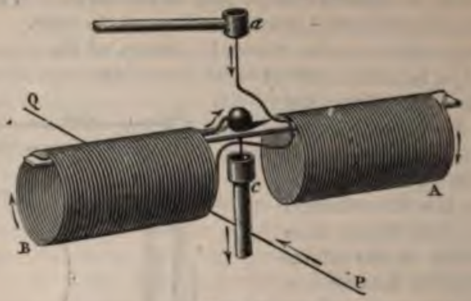


Fig. 654.

moveable about a vertical axis, and if beneath it a rectilinear current be passed, which at the same time traverses the wires of the solenoid, the latter is seen to turn and set at right angles to the lower current—that is, in such a position that its circuits are parallel to the fixed current; and, further, in the lower part of each of the circuits the current is in the same direction as in the rectilinear wire.

If, instead of passing a rectilinear current below the solenoid, it is passed vertically on the side, an attraction or repulsion will take place, according, as in the vertical wire, and in the nearest part of the solenoid, the two currents are in the same or in a contrary direction.

804. **Directive action of the earth on solenoids.**—If a solenoid be suspended in the two cups (fig. 626), not in the direction of the magnetic meridian, and a current be passed through the solenoid, the latter will begin to move, and will finally set in such a position that its axis is in the direction of the magnetic meridian. If the solenoid be removed, it will, after a few oscillations, return, so that its axis is in the magnetic meridian. Further, it will be found that in the lower half of the coils of which the solenoid consists, the direction of the current is from east to west; in other words, the current is *descending* on that side of the coil turned towards the east, and ascending on the west. The directive action of the earth on solenoids is accordingly a consequence of that which it exerts on circular currents. In this experiment the solenoid is directed like a magnetic needle, and the *north pole*, as in magnets, is that end which points towards the north, and the *south pole* that which points towards the south. This experiment may be well made by means of a solenoid fitted on a De la Rive's floating battery.

805. **Mutual action of magnets and solenoids.**—Exactly the same phenomena of attraction and repulsion exist between solenoids and magnet as between magnets. For if to a moveable solenoid traversed by a current, one of the poles of a magnet be presented, attraction or

repulsion will take place, according as the poles of the magnet and of the solenoid are of contrary or of the same name. The same phenomenon takes place when a solenoid traversed by a current and held in the hand is presented to a moveable magnetic needle. Hence the law of attractions and repulsions applies exactly to the case of the mutual action of solenoids and of magnets.

806. **Mutual actions of solenoids.**—When two solenoids traversed by a powerful current are allowed to act on each other, one of them being held in the hand, and the other being moveable about a vertical axis, as shown in fig. 655, attraction and repulsion will take place just as in the case of two magnets. These phenomena are readily explained by reference to what has been said about the mutual action of the currents, bearing in mind the direction of the currents in the extremities presented to each other.

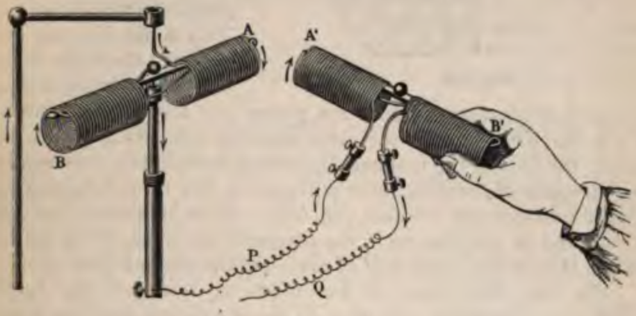


Fig. 655.

807. **Ampère's theory of magnetism.**—Ampère has propounded a most ingenious theory, based on the analogy which exists between solenoids and magnets, by which all magnetic phenomena may be referred to electrodynamical principles.

Instead of attributing magnetic phenomena to the existence of two fluids, Ampère assumes that each individual molecule of a magnetic substance is traversed by a closed electric current. It is further assumed that these molecular currents are free to move about their centres of gravity. The coercive force, however, which is little or nothing in soft iron, but considerable in steel, opposes this motion, and tends to keep them in any position in which they happen to be. When the magnetic substance is not magnetised, these molecular currents, under the influence of their mutual attractions, occupy such positions that their total action on any external substance is null. Magnetisation consists in giving to these molecular currents a parallel direction, and the stronger the magnetising force the more perfect the parallelism. The *limit of magnetisation* is attained when the currents are completely parallel.

The resultant of the actions of all the molecular currents is equivalent to that of a single current which traverses the outside of a magnet. For by inspection of fig. 656, in which the molecular currents are represented by a series of small internal circles in the two ends of a cylindrical bar, it will be seen that the adjacent parts of the currents oppose one another, and cannot exercise any external electrodynamic action. This is not the case with the surface: there the molecular currents at *ab* are not neutralised by other currents, and as the points *abc* are infinitely near, they form a series of elements in the same direction situated in planes perpendicular to the axis of the magnet, and which constitute a true solenoid.

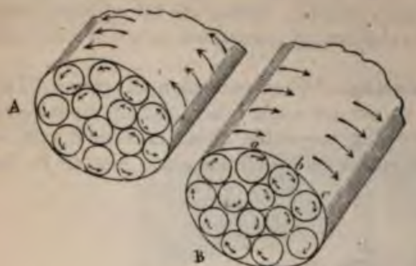


Fig. 656.

The direction of these currents in magnets can be ascertained by considering the suspended solenoid (fig. 655). If we suppose it traversed by a current, and in equilibrium in the magnetic meridian, it will set in such a position that in the lower half of each coil the current flows from *east to west.* We may then establish the following rule. *At the north pole (English) of a magnet the direction of the Ampèrian currents is opposite that of the hands of a watch, and at the south pole the direction is the same as that of the hands.*

808. **Terrestrial current.**—In order to explain on this supposition terrestrial magnetic effects, the existence of electrical currents is assumed which continually circulate round our globe from east to west perpendicular to the magnetic meridian.

The resultant of their action is a single current traversing the magnetic equator from east to west. These currents are supposed to be thermo-electric currents due to the variations of temperature caused by the successive influence of the sun on the different parts of the globe from east to west.

These currents direct magnetic needles; for a suspended magnetic needle comes to rest when the molecular currents on its under surface are parallel, and in the same direction as the earth currents. As the molecular currents are at right angles to the direction of its length, the needle places its greatest length at right angles to east and west, or north and south. Natural magnetisation is probably imparted in the same way to iron minerals.

CHAPTER V.

MAGNETISATION BY CURRENTS. ELECTROMAGNETS. ELECTRIC TELEGRAPHS.

809. **Magnetisation by currents.**—From the influence which currents exert upon magnets, turning the north pole to the left and the south pole to the right, it is natural to think that by acting upon magnetic substances in the natural state the currents would tend to separate the two magnetisms. In fact, when a wire traversed by a current is immersed in iron filings, they adhere to it in large quantities, but become detached as soon as the current ceases, while there is no action on any other non-magnetic metal.

The action of currents on magnetic substances is well seen in an experiment due to Ampère, which consists in coiling an insulated copper wire round a glass tube, in which there is an unmagnetised steel bar. If a current be passed through the wire, even for a short time, the bar becomes strongly magnetised.

If, as we have already seen, the discharge of a Leyden jar be transmitted through the wire, by connecting one end with the outer coating, and the other with the inner coating, the bar is also magnetised. Hence both voltaic and frictional electricity can be used for magnetising.

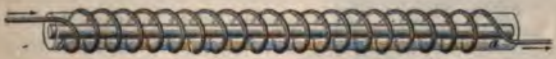


Fig. 657.

If in this experiment the wire be coiled on the tube in such a manner that when it is held vertically the downward direction of the coils is from right to left on the side next the observer, this constitutes a *right-handed* or *dextrorsal spiral* or *helix* (fig. 657), of which the ordinary screw is an example. In a *left-handed* or *sinistrorsal helix* the coiling is in the opposite direction, that is from left to right (fig. 658).

In a right-handed spiral the north pole is at the end at which the

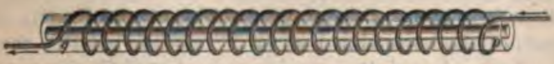


Fig. 658.

current emerges, and the south pole at the end at which it enters; the reverse is the case in a left-handed spiral. But whatever the direction of the coiling, the polarity is easily found by the following rule: *If a person swimming in the current look at the axis of the spiral, the north pole is* *always on his left.* If the wire be not coiled regularly, but its direction be reversed, at each change of direction a consequent point is formed in the magnet. The simplest method of remembering the polarity produced is as follows : Whatever be the nature of the helix, either right or left handed, if the end facing the observer has the current flowing in the direction of the hands of a watch, it is a *south* pole and *vice versâ.* The same polarity is produced, whether or not an iron core be within the helix.

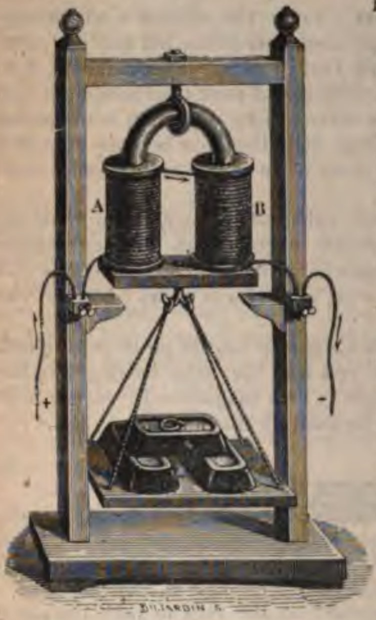


Fig. 659.

The nature of the tube on which the helix is coiled is not without influence. Wood and glass have no effect, but a thick cylinder of copper may greatly affect the action of the current unless the copper be slit longitudinally. This action will be subsequently explained. The same is the case with iron, silver, and tin.

In order to magnetise a steel bar by means of electricity, it need not be placed in a tube, as shown in figs. 657 and 658. It is sufficient to coil round it a copper wire covered with silk, in order to insulate the circuits from one another. The action of the current is thus multiplied, and a feeble current is sufficient to produce a powerful magnetising effect.

810. **Electromagnets.**—*Electromagnets* are bars of soft iron which, under the influence of a voltaic current, become magnets ; but this magnetism is only temporary, for the coercive force of perfectly soft iron is null, and the two magnetisms neutralise each other as soon as the current ceases to pass through the wire. If, however, the iron is not quite pure, it retains more or less traces of magnetism. The electromagnets have the horse-shoe form, as shown in fig. 659, and a copper wire, covered with silk or cotton, is rolled several times round them on the two branches, so as to form two bobbins, A and B. In order that the two ends of the horse-shoe may be of opposite polarity, the winding on the two limbs A and B must be such that if the horse-shoe were straightened out, it would be in the same direction.

Electromagnets, instead of being made in one piece, are frequently constructed of two cylinders, firmly screwed to a stout piece of the same metal. Such are the electromagnets in Morse's telegraph (815), the electromagnetic motor (819). The helices on them must be such that the current shall flow in the same direction as the hands of a watch as seen from the south pole, and against the hands of a watch as seen from the north pole.

The results at which various experiments have arrived as regards the force of electromagnets are often greatly divergent, which is partly due to the different senses they have attached to the notion of *electromagnetic force.* For this may mean (I.) the induction current which the development and disappearance of the magnetism of an iron core indicate in a spiral which surrounds it ; this is the *excited magnetism* ; or (II.) the free magnetism measured by the action on a magnetic needle, oscillating at a distance ; (III.) the *attractive force*, or the force required to hold an armature at a distance from the electromagnet ; (IV.) the *lifting power* measured by the force with which an armature is held in direct contact with the pole.

The most important results which have been arrived at are the following :

(i.) Using the term electromagnetic force in the first two senses, it *is proportional to the intensity of the current.* This only applies when the currents are not very powerful, and to stout bars ; for in each bar there is, as Muller has found, a maximum of magnetisation which cannot be exceeded.

(ii.) Taking into account the resistance, *the electromagnetic force is independent of the nature and thickness of the wire.* Thus the intensity of the current and the number of coils being the same, thick and thin wires produce the same effect.

(iii.) With the same current the *electromagnetic force is independent of the width of the coils*, provided the iron projects beyond the coils, and the diameter of the coil is small compared with its length.

(iv.) The temporary magnetic moment *of an iron bar is within certain limits proportional to the number of windings.* The product of the intensity into the number of turns is usually spoken of as the *magnetising power* of the spiral. The greatest magnetising power is obtained when the resistance in the magnetising spiral is equal to the sum of the other resistances in the circuit, those of the battery included, and the length and diameter of the wire must be so arranged as to satisfy these conditions.

(v.) The magnetism in solid and in hollow cylinders of the same diameters is the same, provided in the latter case there is sufficient iron for the development of the magnetism.

(vi.) The attraction of an armature by an electromagnet is proportional to the square of the intensity of the current so long as the magnetic moment does not attain its maximum. Two unequally strong electromagnets attract each other with a force proportional to the square of the sum of both currents.

(vii.) For powerful currents the length of the branches of an electromagnet is without influence on the weight which it can support.

As regards the quality of the iron used for the electromagnet, it must be pure, and be made as soft as possible by being reheated and cooled a great many times; it is polished by means of a file so as to avoid twisting. If this is not the case the bar retains, even after the passage of the current, a quantity of magnetism which is called the *remanent magnetism*. A bundle of soft iron wires loses its magnetism more rapidly than a massive bar of the same size.

During magnetisation the volume of a magnet does not vary. This has been established by placing the bar to be magnetised, with its helix, in a sort of water thermometer, consisting of a flask provided with a capillary tube. On magnetising no alteration in the position of the water is observed. But the dimensions vary, the diameter is somewhat lessened, and the length increased; according to Joule to the extent of about $\frac{1}{2700}$ if the bar is magnetised to saturation.

We shall presently see the numerous applications which have been made of electromagnets in electric telegraphs, in electromagnetic motors, in electric clocks, and in the study of diamagnetic phenomena.

811. **Vibratory motion and sounds produced by currents.**—When a rod of soft iron is magnetised by a strong electric current, it gives a very distinct sound, which, however, is only produced at the moment of closing or opening the current. This phenomenon, which was first observed by Page in America, and by Delezenne in France, has been particularly investigated by De la Rive, who has attributed it to a vibratory motion of the molecules of iron in consequence of a rapid succession of magnetisations and demagnetisations.

When the current is broken and closed at very short intervals, De la Rive has observed, that whatever be the shape or magnitude of the iron bars, two sounds may always be distinguished: one, which is musical, corresponds to that which the rod would give by vibrating transversely; the other, which consists of a series of harsh sounds, corresponding to the interruptions of the current, is compared by De la Rive to the noise of rain falling on a metal roof. The most marked sound, says he, is that obtained by stretching on a sounding board pieces of soft iron wire, well annealed, from 1 to 2 mm. in diameter, and 1 to 2 yards long. These wires being placed in the axis of one or more bobbins traversed by powerful currents, send forth a number of sounds, which produce a surprising effect, and much resemble that of a number of church bells heard at a distance.

Wertheim has obtained the same sounds by passing a discontinuous current, not through the bobbins surrounding the iron wires, but through the wires themselves. The musical sound is then stronger and more sonorous in general than in the previous experiment. The hypothesis of a molecular movement in the iron wires at the moment of their magnetisation, and of their demagnetisation, is confirmed by the researches of Wertheim, who has found that their elasticity is then diminished.

ELECTRIC TELEGRAPH.

812. **Electric telegraphs.**—These are apparatus by which signals can be transmitted to considerable distances by means of voltaic currents propagated in metallic wires. Towards the end of the last century, and at the beginning of the present, many philosophers proposed to correspond at a distance by means of the effects produced by electrical machines when propagated in insulated conducting wires. In 1811, Sœmmering invented a telegraph in which he used the decomposition of water for giving signals. In 1820, at a time when the electromagnet was unknown, Ampère proposed to correspond by means of magnetic needles, above which a current was sent, as many wires and needles being used as letters were required. In 1834, Gauss and Weber constructed an electromagnetic telegraph, in which a voltaic current transmitted by a wire acted on a magnetised bar; the oscillations of which under its influence were observed by a telescope. They succeeded in thus sending signals from the Observatory to the Physical Cabinet in Göttingen, a distance of a mile and a quarter, and to them belongs the honour of having first demonstrated experimentally the possibility of electrical communication at a considerable distance. In 1837, Steinheil in Munich, and Wheatstone in London, constructed telegraphs in which several wires each acted on a single needle; the current in the first case being produced by an electromagnetic machine, and in the second by a constant battery.

Every electric telegraph consists essentially of three parts: 1, a *circuit* consisting of a metallic connection between two places, and an *electromotor* for producing the current; 2, a *communicator* for sending the signals from the one station; and, 3, an *indicator* for receiving them at the other station. The manner in which these objects, more especially the last two, are effected can be greatly varied, and we shall limit ourselves to a description of the three principal methods.

The electromotor generally used in England is a modification of Wollaston's battery. It consists of a trough divided into compartments, in each of which is an amalgamated zinc plate and a copper plate; these plates are usually about 4½ inches in height by 3½ in breadth. The compartments are filled with sand, which is moistened with dilute sulphuric acid. This battery is inexpensive and easily worked, only requiring from time to time the addition of a little acid; but it has very low electromotive force and considerable resistance, and when it has been at work for some time, the effects of polarisation begin to be perceived. On the telegraphs of the South Eastern Railway, the platinised graphite (746) battery invented by Mr. C. V. Walker is used with success. In France, Daniell's battery is used for telegraphic purposes.

The connection between two stations is made by means of galvanised

iron wire suspended by porcelain supports, which insulate and pro
them against the rain, either on posts or against the sides of buildi
In towns, wires covered with gutta-percha are placed in tubes laid in
ground. Submarine cables are formed of copper wires for the sak
the greater conductivity. These wires are coated with gutta-perc
round which is a coating of tarred hemp, the whole being surrounded
an iron cable, which gives it strength to resist the tension at the momen
laying the cable, and to enable it to resist the action of submarine curre

At the station which sends the despatch, the line is connected with
positive pole of a battery, the current passes by the line to the other stati

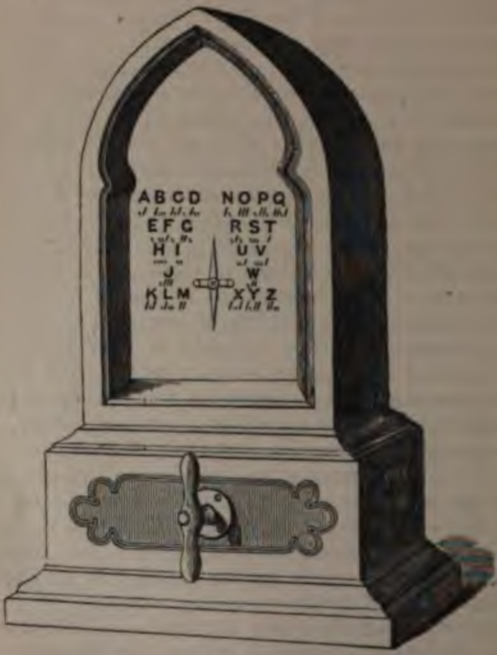


Fig. 660.

and if there were a second return line, it would traverse it in the opp
direction to return to the negative pole. In 1837, Steinheil made the
important discovery that the earth might be used for the return condu
thereby saving the expense of the second line. For this purpose the
of the conductor at the one station, and the negative pole of the ba
at the other, are connected with large copper plates, which are sun
some depth in the ground. The action is then the same as if the
acted as a return wire. The earth is, indeed, far superior to a r
wire; for the added resistance of such a wire would be consider

s the resistance of the earth beyond a short distance is absolutely
he earth really *dissipates* the electricity, and does not actually
the same current to the battery.

Wheatstone's and Cooke's single needle telegraph.—This con-
ssentially of a vertical multiplier with an astatic needle, the arrange-
f which is seen in fig. 661, while fig. 660 gives a front view of the
which the apparatus is placed. A (fig. 661) is the bobbin con-

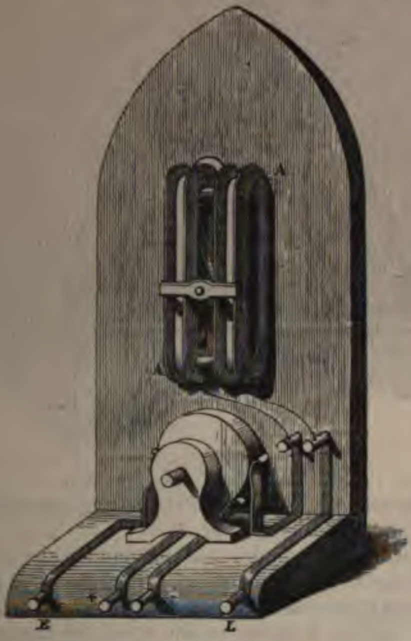


Fig. 661.

of about 400 feet of fine copper wire, wound in a frame in two con-
coils. Instead of an astatic needle, Mr. Walker has found it
ageous to use a single needle formed of several pieces of very thin
trongly magnetised; it works within the bobbin, and a light index
to it by a horizontal axis indicates the motion of the needle on the

signs are made by transmitting the current in different directions
h the multiplier, by which the needle is deflected either to the right
according to the will of the operator. The instrument by which
effected is a *commutator* or *key*, G; its construction is shown in
, while fig. 662 shows on a large scale how two stations are con-
. It consists of a cylinder of boxwood with a handle, which
ts in front of the case (fig. 660). On its circumference parallel to

the axis are seven brass strips (fig. 662), the spaces between which are insulated by ivory; these strips are connected at the end by metallic wires, also insulated from each other, in the following manner: *a* with *b* and *c*, *f* with *d*, and *e* with *g*. Four springs press against the cylinder; *x*

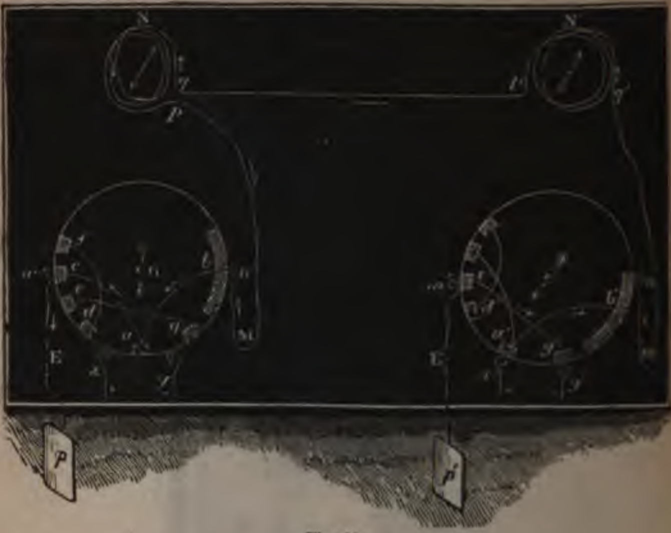


Fig. 662.

and *y* are connected with the poles of the battery, *m* with the earth plate, and *n* with one end of the multiplier, N.

When not at work the cylinder and the handle are in a vertical position, as seen on the left of the diagram. The circuit is thus *open*, for the pole springs, *x* and *y*, are not connected with the metal of the commutator. But if, as in G′, the key is turned to the right, the battery is brought into the circuit, and the current passes in the following direction: + pole $x'a'b'n'M'q'$, conductor $qMnbacmEp$, earth $p'Em'e'g'y'$ − pole. The coils N and N′ are so arranged that by the current the motion of the needle corresponds to the motion of the handle. By turning the handle to the left the current would have the following direction: + pole $x'd'f'm'E'p'$, earth $pEmcabnMq$, conductor $q'M'n'b'a'y'$ − pole, and thus the needle would be deflected in the opposite direction.

The signs are given by differently combined deflections of the needle, as represented in the alphabet on the dial (fig. 660). ╲ denotes a deflection of the upper end of the needle to the left, and ╱ a deflection to the right; I, for instance, is indicated by two deflections to the left, and M by two to the right. Some of the marks on the alphabet are only half as long as the others; this indicates that the shortest of the connected marks must first be signalled. Thus, D is expressed by right-left-left, and C by right-left-right-left, etc.

These signs are somewhat complicated, and require great practice; usually not more than 12 to 20 words can be sent in a minute. Hence the single needle telegraph is in many cases replaced by the double needle one, which is constructed on the same principle, but there are two needles and two wires instead of one.

814. **Dial telegraphs.**—Of these many kinds exist. Figs. 664 and 665 represent a lecture-model of one form, constructed by M. Froment, and which well serves to illustrate the principle. It consists of two parts: the *manipulator* for transmitting signals (fig. 664), and the *indicator* (fig. 665) for receiving them. The first apparatus is connected with a battery, Q, and the two apparatus are in communication by means of metallic wires, one of which, AOD (fig. 664), goes from the departure to the arrival station, and the other, HKLI (fig. 665), from the arrival to the departure. In practice, the latter is replaced by the earth circuit. Each apparatus is furnished with a dial with 25 of the letters of the alphabet, on which a needle moves. The needle at the departure station is moved by hand, that of the arrival by electricity.

The path of the current and its effects are as follows: From the battery it passes through a copper wire, A (fig. 664), into a brass spring N, which presses against a metal wheel, R, then by a second spring, M, into the wire, O, which joins the other station. Thence the current passes into the bobbin of an electromagnet, *b*, not fully shown in fig. 665, but of which fig. 663 represents a section, showing the anterior part of the apparatus. This electromagnet is fixed horizontally at one end, and at the other it attracts an armature of soft iron, *a*, which forms part of a bent lever, moveable about its axis, *o*, while a spring, *r*, attracts the lever in the opposite direction.

When the current passes, the electromagnet attracts the lever *a*C, which by a rod, *i*, acts on a second lever, *d*, fixed to a horizontal axis, itself connected with a fork, F. When the current is broken the spring *r* draws the lever *a*C, and therewith all the connected pieces; a backward and forward motion is produced, which is communicated to the fork F, which transmits it to a toothed wheel, G, on the axis of which is the needle. From the arrangement of its teeth, the wheel G is always moved in the same direction by the fork.

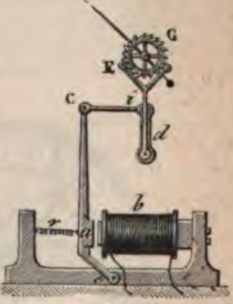


Fig. 663.

To explain the intermittent action of the magnet, we must refer to fig. 664. The toothed wheel, R, has 26 teeth, of which 25 correspond to letters of the alphabet, and the last to the interval reserved between the letters A and Z. When holding the knob P in the hand the wheel R is turned, the end of the plate N from its curvature is always in contact with the teeth; the plate M, on the contrary, terminates in a catch cut so that contact is alternately made and broken. Hence the connections with the battery having been made, if the needle P is advanced through four letters, for example, the current passes four times in N and M, and four times broken. The electromagnet of the arrival station will then ha

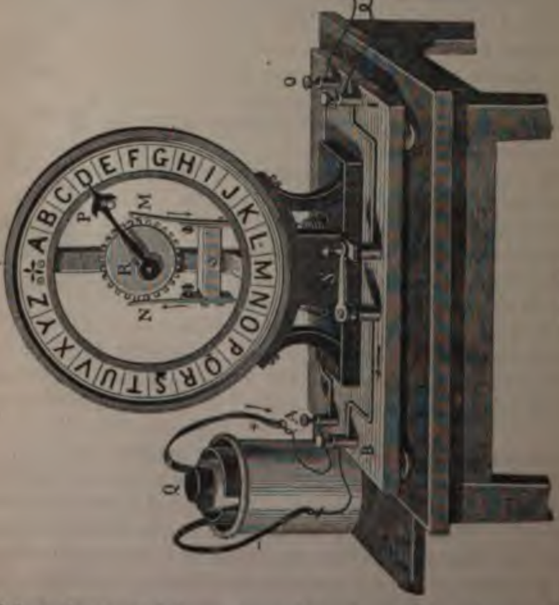


Fig. 664.

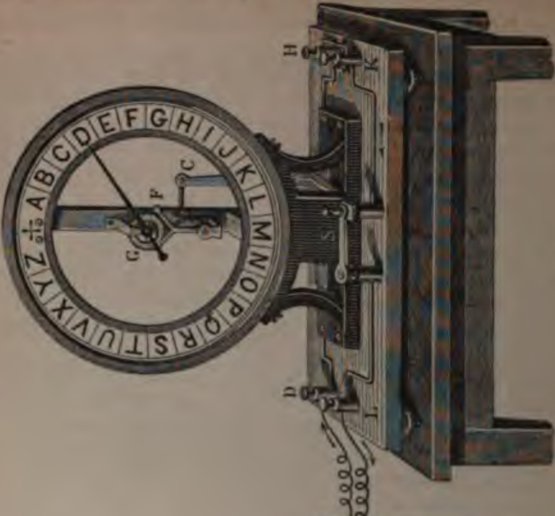


Fig. 665.

attracted four times, and have ceased to do so four times. Lastly, th wheel G will have turned by four teeth, and as each tooth correspond a letter, the needle of the arrival station will have passed through exactly the same number of letters as that of the departure station. The piece S, represented in the two figures, is a copper plate, moveable on a hinge, which serves to make or to break the current at will.

From this explanation it will be readily intelligible how communications are made between different places. Suppose, for example, that the first apparatus being at London and the second at Brighton, there being metallic connection between the two towns, it is desired to send the word *signal* to the latter town : as the needles correspond on each apparatus to the interval retained between A and Z, the person sending the despatch moves the needle P to the letter S, where it stops for a very short time ; as the needle at Brighton accurately reproduces the motion of the London needle, it stops at the same letter, and the person who receives the despatch notes this letter. The one at London always continuing to turn in the same direction, stops at the letter I, the second needle immediately stops at the same letter ; and continuing in the same manner with the letters G, N, A, L, all the word is soon transmitted to Brighton. The attention of the observer at the arrival station is attracted by means of an electric alarum. Each station further must be provided with the two apparatus (figs. 663 and 664), without which it would be impossible to answer.

815. **Morse's telegraph.**—The telegraphs hitherto described leave no trace of the despatches sent, and if any errors have been made in copying the signals there is no means of remedying them. These inconveniences are not met with in the case of the *writing telegraphs*, in which the signs themselves are printed on a strip of paper at the time at which they are transmitted.

Of the numerous printing and writing telegraphs which have been devised, that of Mr. Morse, first brought into use in North America, is best known. It has been almost universally adopted on the Continent. In this instrument there are three distinct parts : the *indicator*, the *communicator*, and the *relay* ; figs. 666, 667, and 668 represent these apparatus.

Indicator. We will first describe the indicator (fig. 666), leaving out of sight for the moment the accessory pieces, G and T, placed on the right of the figure. The current which enters the indicator by the wire, C, passes into an electromagnet, E, which, when the current is closed, attracts an armature of soft iron, A, fixed at the end of a horizontal lever moveable about an axis, x; when the current is open the lever is raised by a spring, r. By means of two screws, m and v, the amplitude of the oscillations is regulated. At the other end of the lever there is a pencil, p, which writes the signals. For this purpose a long band of strong paper, pp, rolled round a drum, R, passes between two copper rollers with a rough surface, u, and turning in contrary directions. Drawn in the direction of the arrows, the band of paper becomes rolled on a second drum, Q, which is turned by hand. A clockwork motion placed in the box, BD, works the rollers, between which the band of paper passes.

The paper being thus set in motion, whenever the electromagnet works, the point *o* strikes the paper, and, without perforating it, produces an indentation, the shape of which depends on the time during which the

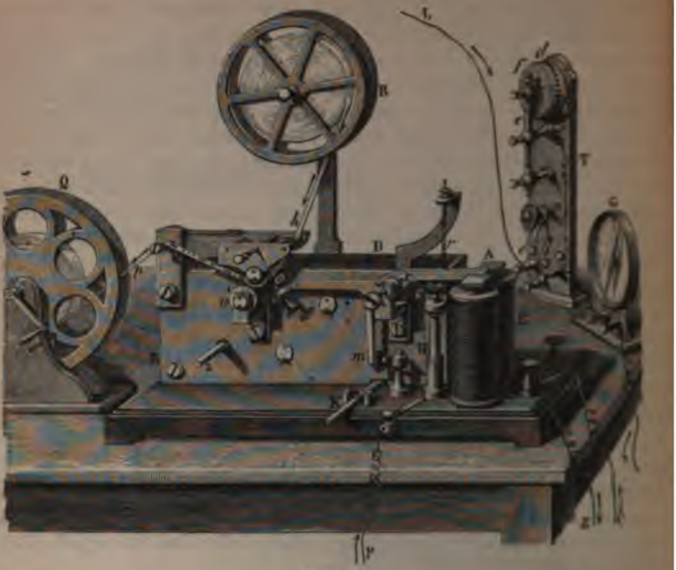


Fig. 666.

point is in contact with the paper. If it only strikes it instantaneously, makes a *dot* (.) or short stroke (–); but if the contact has any duration *dash* of corresponding length is produced. Hence, by varying the lengt of contact of the transmitting key at one station, a combination of do and dashes may be produced at another station, and it is only necessar to give a definite meaning to these combinations.

The same telegraphic alphabet is now universally used wherever tel graphic communication exists; and the signals for the single needle i strument (fig. 660), as well as those used for printing have been modifie so that they now correspond to each other. Thus a beat of the top the needle to the left ╲ is equivalent to a dot; and a beat to the right to a dash. The figure on the following page gives the alphabet :—

Communicator or key. This consists of a small mahogany base, whi acts as support for a metallic lever *ab* (fig. 667), moveable in its middle a horizontal axis. The extremity *a* of this lever is always pressed wards by a spring beneath, so that it is only by pressing with the fing on the key B that the lever sinks and strikes the bottom *x*. Round t base there are three binding screws; one connected with the wire which comes from the positive pole of the battery; the second connect with L, the wire of the line; and the third with the wire A, which pass

:he indicator, for of course two places in communication are each pro-
ed with an indicator and communicator.

PRINTING.		SINGLE NEEDLE.		PRINTING.		SINGLE NEEDLE.
A	-—	\/		N	—-	/\
B	—---	/\\\		O	———	///
C	—-—-	/\/\		P	-——-	\//\
D	—--	/\\		Q	——-—	//\/
E	-	\		R	-—-	\/\
F	--—-	\\/\		S	---	\\\
G	——-	//\		T	—	/
H	----	\\\\		U	--—	\\/
I	--	\\		V	---—	\\\/
J	-———	\///		W	-——	\//
K	—-—	/\/		X	—--—	/\\/
L	-—--	\/\\		Y	—-——	/\//
M	——	//		Z	——--	//\\

Fhese details known, there are two cases to be considered: 1. The nmunicator is arranged so as to receive a despatch from a distant st; the extremity *b* is then depressed, as represented in the drawing, that the current which arrives by the wire of the line L, and ascends

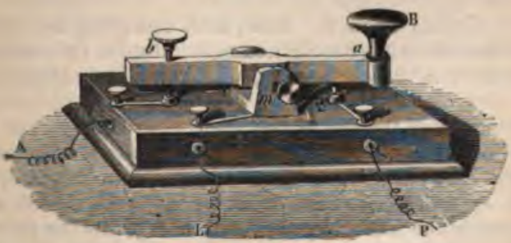


Fig. 667.

the metallic piece *m*, redescends in the wire A, which leads it to the icator of the post at which the apparatus is placed. 2. A despatch is be transmitted; in this case the key B is pressed so that the lever nes in contact with the button *x*. The current of the local battery, ich comes by the wire P, ascending then in the lever, redescends by *m* and joins the wire L, which conducts it to the post to which the despatch is addressed. According to the length of time during which B is pressed, a dot or a line is produced in the receiver to which the current proceeds.

Relay. In describing the receiver we have assumed that the current of the line coming by the wire C (fig. 666) entered directly into the electromagnet, and worked the armature A, producing a despatch; but when the current has traversed a distance of a few miles its intensity has diminished so greatly that it cannot act upon the electromagnet with sufficient force to print a despatch. Hence it is necessary to have recourse to a relay—that is, to an auxiliary electromagnet which is still traversed by the current of the line, but which serves to introduce into the communicator the current of a *local battery* of 4 or 5 elements placed at the station, and which is only used to print the signals transmitted by the wire.

For this purpose the current entering the relay by the binding screw, L (fig. 668), passes into an electromagnet, E, whence it passes into the earth by the binding screw T. Now, each time that the current of the line passes into the relay, the electromagnet attracts an armature, A, fixed at the bottom of a vertical lever *p*, which oscillates about a horizontal axis.

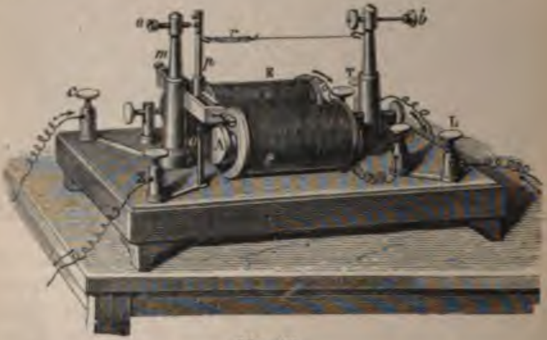


Fig. 668.

At each oscillation the top of the lever *p* strikes against a button, *n*, and at this moment the current of the local battery which enters by the binding screw, *c*, ascends the column *m*, passes into the lever *p*, descends by the rod *o*, which transmits it to the screw Z: thence it enters the electromagnet of the indicator, whence it emerges by the wire Z, to return to the local battery from which it started. Then when the current of the line is open, the electromagnet of the relay does not act, and the lever *p*, drawn by a spring *r*, leaves the button *n*, as shown in the drawing, and the local current no longer passes. Thus the relay transmits to the indicator exactly the same phases of passage and intermittence as those effected by the manipulator in the post which sends the despatch.

With a general battery of 25 Daniell's elements the current is strong enough at upwards of 90 miles from its starting-point to work a relay. For a longer distance a new current must be taken, as will be seen in the paragraph on the change of current (*vide infra*).

Working of the three apparatus. The three principal pieces of Morse's apparatus being thus known, the following is the actual path of the current.

The current of the line coming by the wire L (fig. 66~~8~~) passes at first 6/ to the piece T intended to serve as lightning conductor, when, from the influence of atmospheric electricity in time of storm, the conducting wires become charged with so much electricity as to give dangerous sparks. This apparatus consists of two copper discs, *d* and *f*, provided with teeth on the sides opposite each other, but not touching. The disc *d* is connected with the earth by a metallic plate at the back of the stand which supports this lightning conductor, while the disc *f* is in the current. The latter coming by the line L enters the lightning conductor by the binding screw fixed at the lower part of the stand on the left; then rises to a commutator, *n*, which conducts it to a button, *c*, whence it reaches the disc *f* by a metallic plate at the back of the stand; in case a lightning discharge should pass along the wire, it would now act inductively on the disc *d*, and emerge by the points without danger to those about the apparatus. Moreover, from the disc *f*, the current passes into a very fine iron wire insulated on a tube *e*. As the wire is melted, when the discharge is too intense, the electricity does not pass into the apparatus, which still further removes any danger.

Lastly, the current proceeds from the foot of the support *s* to a screw on the right, which conducts it to a small galvanometer, G, serving to indicate by the deflection of the needle whether the current passes. From this galvanometer the current proceeds to a communicator (fig. 667), which it enters at L, whence it emerges at A to go to the relay (fig. 668). Entering this at L, it works the electromagnet, and establishes the communication necessary for the passage of the current of the local battery, as has been said in speaking of the relay.

Change of current. To complete this description of Morse's apparatus it must be observed that in general the current which arrives at L, after having traversed 6 miles, has not sufficient force to register the despatch, nor to proceed to a new distant point. Hence, in each telegraphic station a new current must be taken, that of the *postal battery*, which consists of 20 to 30 Daniell's elements, and is not identical with the *local battery*.

This new current enters at P (fig. 666), reaches a binding screw which conducts it to the column H, and thence only proceeds further when the armature A sinks. A small contact placed under the lever touches then the button *v*; the current proceeds from the column H to the metallic mass BD, whence by a binding screw and a wire, not represented in the figure, it reaches lastly the wire of the line, which sends it to the following post, and so on from one point to another.

816. **Induction in telegraph cables.**—In the earliest experiments on the use of insulated subterranean wires for telegraphic communication it was found that difficulties occurred in their use which were not experienced with overland wires. This did not arise from defective insulation, for the better the insulation the greater the difficulty. It was suspected by Siemens and others that the retardation was due to statical induction taking place between the inner wire through the insulator and the external moisture; and that this was the case Faraday proved by the following experiments among others. A length of about 100 miles of gutta-percha covered copper wire was immersed in water, the ends being led into the chamber of observation. When the pole of a battery containing a large number of cells was momentarily connected with one end of the wire, the other end being insulated, and a person simultaneously touched the wire and the earth contact, he obtained a violent shock.

When the wire, after being in momentary contact with the battery, was placed in connection with a galvanometer, a considerable deflection was observed; there was a feebler one 3 or 4 minutes after, and as long as 20 or 30 minutes afterwards.

When the insulated galvanometer was permanently connected with one end of the wire, and then the free end of the galvanometer wire joined to the pole of the battery, a rush of electricity through the galvanometer into the wire was perceived. This speedily diminished and the needle ultimately came to rest. When the galvanometer was detached from the battery and put to earth, the electricity flowed as rapidly out of the wire, and the needle was momentarily deflected in the opposite direction.

These phenomena are not difficult to explain. The wire with its thin insulating coating of gutta-percha becomes statically charged with electricity from the battery. The coating of gutta-percha through which the inductive action takes place is only $\frac{1}{12}$ of an inch in thickness, and the extent of the coatings is very great. The surface of the copper wire amounts to 8,300 square feet, and that of the outside coating is four times as much. The tension can only be as great as that of the battery, but from the enormous surface the quantity is very great. Thus the wires, after being detached from the battery, showed all the actions of a powerful electric battery. These effects cannot take place with wires in air, for the external coating is wanting, or at all events is so distant that induction and charge cannot occur.

Hence the difficulty in submarine telegraphy. The electricity which enters the insulating wire must first be used in charging the large Leyden jar which it constitutes, and only after this has happened can the current reach the distant end of the circuit. The current begins later at the distant end, and ceases sooner. If the electrical currents follow too rapidly, an uninterrupted current will appear at the other end, which indicates small differences in strength, but not with sufficient clearness differences in duration or direction. Hence in submarine wires the signals must be slower than in air wires to obtain clear indications. By the use of alternating currents—that is, of currents which are alternately positive and negative—their disturbing influences may be materially lessened, and communication be accelerated and made more certain, but they can never be entirely obviated.

In the Atlantic Cable instruments on the principle of Thomson's reflecting galvanometer are used for the reception of signals, the motions of the spot of light to the right and left forming the basis of the alphabet.

817. **Bain's electrochemical telegraph.**—If a strip of paper be soaked in an aqueous solution of ferrocyanide of potassium and connected with the negative pole of a battery, and if the other face be touched with a steel pointer connected with the positive pole, a blue mark due to the formation of some Prussian blue will be formed about the iron, so long as the current passes. The first telegraph based on this principle was invented by Mr. Bain. The alphabet is the same as Morse's, but the despatch is first composed at the departure station on a long strip of ordinary paper. It is perforated successively by small round and elongated holes, which correspond respectively to the dots and marks. This strip of paper is interposed between a small metal wheel and a metal spring, both forming part of the circuit. The wheel in turning carries with it the paper strip, all parts of which pass successively between the wheel and the plate. If the strip were not perforated, it would, not being a conductor, constantly offer a resistance to the passage of the current; but, in consequence of the holes, every time one of them passes there is contact between the wheel and the plate. Thus the current works the relay of the post to which it is sent, and traces in blue, on a paper disc, impregnated with ferrocyanide of potassium, the same series of points and marks as those on the perforated paper.

818. **Electrical clocks.**—Electrical clocks are clockwork machines, in which an electromagnet, by means of an electric current regularly interrupted, is both the motor and the regulator. Fig. 669 represents the face of such a clock, and fig. 670 the mechanism, which works the needles.

An electromagnet, B, attracts an armature of soft iron, P, moveable on a pivot, *a*. The armature P transmits its oscillating motion to a lever, *t*, which, by means of a ratchet, *n*, turns the wheel, A. This, by the pinion, D, turns the wheel C, which by a series of wheels and pinions moves the hands. The small one marks the hours, the large one the minutes; but as the latter does not move regularly, but by sudden starts from second to second, it follows that it may also be used to indicate the seconds.

It is obvious that the regularity of the motion of the hands depends on the regularity of the oscillations of the piece P. For this purpose, the oscillations of the current, before passing into the electromagnet B, are regulated by a standard clock, which itself has been previously regulated by a seconds pendulum. At each oscillation of the pendulum the current is open and closed, and thus the armature P beats seconds exactly.

To illustrate the use of these electrical clocks, suppose that on the railway from London to Birmingham each station has an electric clock, and that from the London station a conducting wire passes to all th clocks on the line as far as Birmingham. When the current passes a this wire all the clocks will simultaneously indicate the same hour, the same minute, and the same second; for electricity travels with suc

Fig. 669.

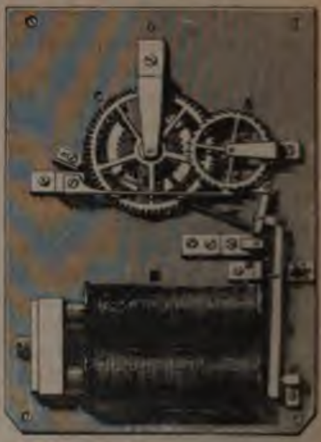


Fig. 670.

enormous velocity, that it takes an inappreciable time to go from Lond to Birmingham.

819. **Electromagnetic machines.**—Numerous attempts have bee made to apply electromagnetism as a motive force in machines. Fi 671 represents a machine of this kind constructed by M. Froment. consists of four powerful electromagnets, ABCD, fixed on an iron fra X. Between these electromagnets is a system of two iron wheels mov able on the same horizontal axis, with eight soft iron armatures, M, o their circumference.

The current arrives at K, ascends in the wire E, and reaches a meta arc, O, which serves to pass the current successively into each elec magnet, so that the attractions exerted on the armatures M shall alw be in the same direction. Now this can only be the case provided th current is broken in each electromagnet just when an armature come front of the axis of the bobbin. To produce this interruption the ar has three branches, *e*, each terminating with a steel spring, to which small sheave is attached. Two of these establish the communicati respectively with an electromagnet, and the third with two. On central wheel, *a*, there are cogs, on which the sheaves alternately re Whenever one of them rests on a cog, the current passes into the cor sponding electromagnet, but ceases to pass when there is no longer co tact. On emerging from the electromagnets the current passes to th negative pole of the battery by the wire H.

In this manner, the armatures M being successively attracted by th ur electromagnets, the system of wheels which carries them assumes a pid rotatory motion, which by the wheel P and an endless band is

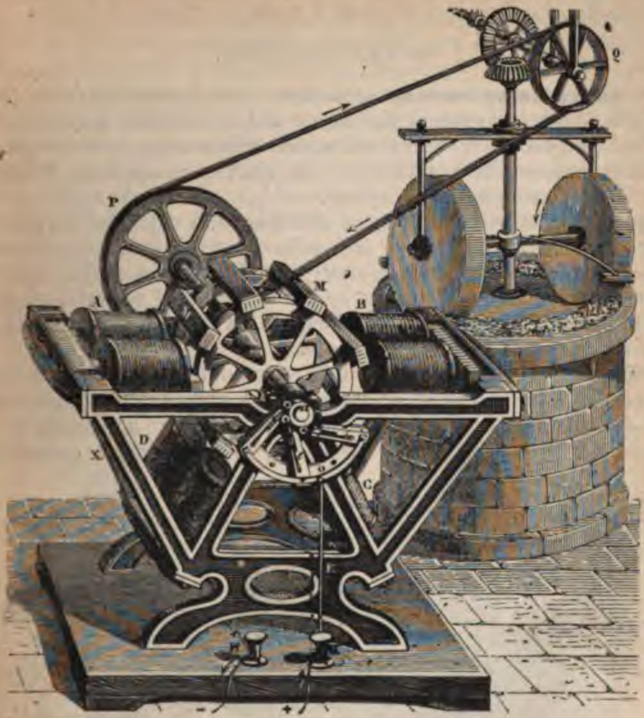


Fig. 671.

ansmitted to a sheave, Q, which sends it finally to any machine, a rinding mill for example.

In his workshops M. Froment has an electromotive engine of one-orse power. But as yet these machines have not been applied in anufactures, for the expense of the acids and the zinc which they use ery far exceeds that of the coal in steam engines of the same force. ntil some cheaper source of electricity shall have been discovered there no expectation that they can be applied at all advantageously.

Thus a machine devised by Kravogl produces about 17 per cent. of e useful effect due to the zinc, and therefore in utilising this force they re about equal to the best steam engines. But a pound of coal yields 7,200 ermal units, and a pound of zinc only 1,200; and as zinc is ten times as ear as coal, electromotor engines are sixty times as dear as steam ngines.

CHAPTER VI.

VOLTAIC INDUCTION.

820. **Induction by currents.**—We have already seen (684) that the name *induction* is meant the action which electrified bodies ex a distance on bodies in the natural state. Hitherto we have only ha deal with electrostatical induction; we shall now see that dynam electricity produces analogous effects.

Faraday discovered this class of phenomena in 1832, and he gave name of *currents of induction* or *induced currents* to instantaneous cur developed in metallic conductors under the influence of metallic condu traversed by electric currents, or by the influence of powerful mag or even by the magnetic action of the earth; and the currents which rise to them he called *inducing currents.*

The inductive action of a current at the moment of opening or cl may be shown by means of a bobbin with two wires. This consists 672) of a cylinder of wood or of cardboard, on which a quantity of covered No. 16 copper wire is coiled; on this is coiled a consider

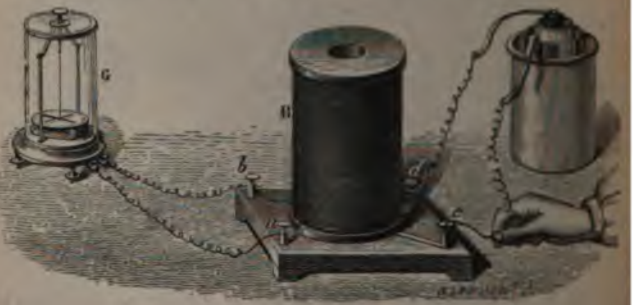


Fig. 672.

greater length of fine copper wire, about No. 35, also insulated by covered with silk. This latter coil, which is called the *secondary* connected by its ends with two binding screws, *a*, *b*, from which pass to a galvanometer, while the thicker wire, the *primary coil*, is nected by its extremities with two binding screws, *c* and *d*. On these, *d*, being connected with one pole of a battery, when a wire the other pole is connected with *c*, the current passes in the primary and in this alone. The following phenomena are then observed:—

i. At the moment at which the thick wire is traversed by the the galvanometer by the deflection of the needle indicates the ex in the *secondary coil* of a current *inverse* to that in the primary coil, is, in the contrary direction; this is only instantaneous, for the immediately reverts to zero, and remains so long as the inducing current passes through *cd*.

ii. At the moment at which the current is opened, that is, when the wire *cd* ceases to be traversed by a current, there is again produced in the wire *ab* an induced current instantaneous like the first, but *direct*, that is, in the same direction as the inducing current.

821. **Production of induced currents by continuous ones.**—Induced currents are also produced when a primary coil traversed by a current is approached to or removed from a secondary one: this may be shown by the following apparatus, fig. 673, in which B is a hollow coil consisting of a great length of fine wire, and A a coil consisting of a shorter and thicker wire, and of such dimensions that it can be placed in the secondary coil.

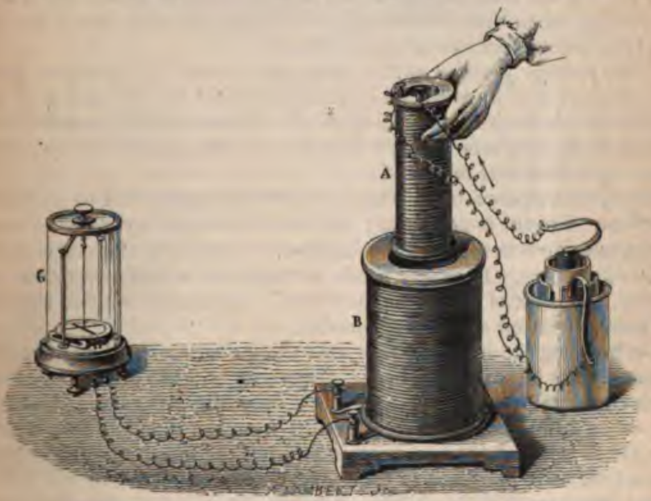


Fig. 673.

The coil A being traversed by a current, if it is suddenly placed in the coil B, a galvanometer connected with the latter indicates by the direction of its deflection the existence in it of an *inverse* current; this is only instantaneous, the needle rapidly returns to zero, and remains so long as the small bobbin is in the large one. If it is rapidly withdrawn, the galvanometer shows that the wire is traversed by a direct current. If, instead of rapidly introducing or replacing the primary coil, this is done slowly, the galvanometer only indicates a weak current, and which is the feebler the slower the motion.

If, instead of varying the distance of the inducing current, its intensity be varied, that is, either increased by bringing additional battery power into the circuit, or diminished by increasing the resistance, an induced current is produced in the secondary wire, which is inverse if the intensity of the inducing current increases and direct if it diminishes.

822. **Conditions of induction. Lenz's law.**—From the experiments which have been described in the previous paragraphs the following principles may be deduced:—

I. The distance remaining the same, *a continuous and constant current does not induce any current in an adjacent conductor.*

II. *A current at the moment of being closed produces in an adjacent conductor an inverse current.*

III. *A current at the moment it ceases produces a direct current.*

IV. *A current which is removed, or whose intensity diminishes, gives rise to a direct induced current.*

V. *A current which is approached, or whose intensity increases, gives rise to an inverse induced current.*

VI. On the induction produced between a close circuit and a current in activity, when their relative distance varies, Lenz has based the following law, which is known as *Lenz's law*:—

If the relative position of two conductors A and B be changed, of which A is traversed by a current, a current is induced in B in such a direction, that by its electrodynamic action on the current in A, it would have imparted to the conductors a motion of the contrary kind to that by which the inducing action was produced.

Thus, for instance, in V, when a current is approached to a conductor, an inverse current is produced; but two conductors traversed by currents in opposite directions, *repel* one another according to the received law of electrodynamics. Inversely when a current is *moved away from* a conductor, a current of the same direction is produced; but two currents in the same direction *attract* one another.

On bringing the inducing wire near the induced as well as in removing it away work is required; hence a quantity of heat proportional to the work consumed must result, as Edlund's investigations have shown. On the other hand, when induction results from the opening and closing of the circuit (II. and III.) no work is lost, but the inducing current loses as much heat as is produced in the induced circuit.

823. **Inductive action of the Leyden discharge.**—Figure 674 represents an apparatus devised by Matteucci, which is very well adapted for showing the development of induced currents produced either by the discharge of a Leyden jar or by the passage of a voltaic current.

It consists of two glass plates about 12 inches diameter, fixed vertically on the two supports A and B. These supports are on moveable feet, and can either be approached or removed at will. On the anterior face of the plate A are coiled about 30 yards of copper wire, C, a millimeter in diameter. The two ends of this wire pass through the plate, one in the centre, the other near the edge, terminating in two binding screws, like those represented in *m* and *n*, on the plate B. To these binding screws are attached two copper wires, *c* and *d*, through which the inducing current is passed.

On the face of the plate B, which is towards A, is enrolled a spiral of much finer copper wire than the wire C. Its extremities terminate in the binding screws *m* and *n*, on which are fixed two wires, *h* and *i*, intended to transmit the induced current. The two wires on the plates are not only covered with silk, but each circuit is insulated from the next one by

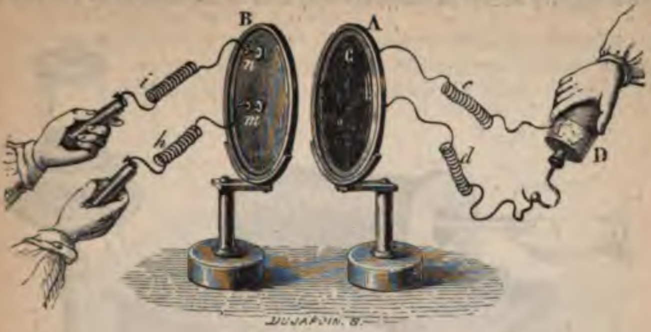


Fig. 674.

a thick layer of shellac varnish, a condition necessary in experimenting with statical electricity, which is always more difficult to insulate than that of the voltaic current, in consequence of its greater tension.

In order to show the production of the induced current by the discharge of a Leyden jar, one end of the wire C is connected with the outer coating, and the other end with the knob of the Leyden jar, as shown in the figure. When the spark passes, the electricity traversing the wire C acts by induction on the neutral fluid of the wire on the plate B, and produces an instantaneous current in this wire. A person holding two copper handles connecting with the wires *i* and *h*, receives a shock, the intensity of which is greater in proportion as the plates A and B are nearer. This experiment proves that frictional electricity can give rise to induced currents as well as voltaic electricity.

The above apparatus can also be used to show the production of induced currents by the influence of voltaic currents. For this purpose the current of a battery is passed through the inducing wire C, while the ends of the other wire, *h* and *i*, are connected with a galvanometer. At the moment at which the current commences or finishes, or when the distance of the two conductors is varied, the same phenomena are observed as in the case of the apparatus (820).

824. **Induction by magnets.**—It has been seen that the influence of a current magnetises a steel bar; in like manner a magnet can produce induced currents in metallic circuits. Faraday has shown this by means of a coil with a single wire of 200 to 300 yards in length. The two extremities of the wire being connected with a galvanometer, as shown in fig. 675, a strongly magnetised bar is suddenly inserted in the bobbin, and the following phenomena are observed :—

i. At the moment at which the magnet is introduced, the galvanometer indicates in the wire the existence of a current, the direction of which is opposed to that which circulates round the magnet, considering the latter as a solenoid on Ampère's theory (807).

ii. When the bar is withdrawn, the needle of the galvanometer, which has returned to zero, indicates the existence of a direct current.

The inductive action of magnets may also be illustrated by the following

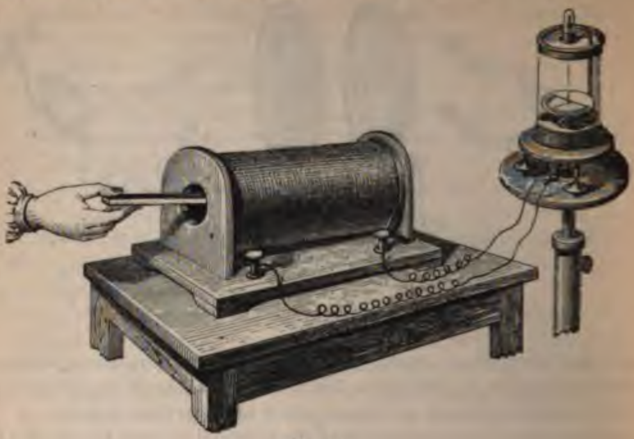


Fig. 675.

experiment: a bar of soft iron is placed in the above bobbin and a strong magnet suddenly brought in contact with it; the needle of the galvanometer is deflected, but returns to zero when the magnet is stationary, and is deflected in the opposite direction when it is removed. The induction is here produced by the magnetisation of the soft iron bar in the interior of the bobbin under the influence of the magnet.

The same inductive effects are produced in the wires of an electromagnet, if a strong magnet be made to rotate rapidly in front of the extremities of the wire in such a manner that its poles act successively by influence on the two branches of the electromagnet: or also by forming two coils round a horse-shoe magnet, and passing a plate of soft iron rapidly in front of the poles of the magnet; the soft iron becoming magnetic reacts by influence on the magnet, and induced currents are produced in the wire alternately in different directions.

The inductive action of magnets is a striking confirmation of Ampère's theory of magnetism. For as in this theory all magnets are solenoids, all the experiments which have been mentioned may be explained by the inductive action of currents which traverse the surface of magnets; the induction of magnets is in short an induction of currents. And it is a useful exercise to see how on this view the inductive action of magnets falls under Lenz's law (822).

825. **Inductive action of magnets on bodies in motion.**—Arago was the first to observe, in 1824, that the number of oscillations which a magnetised needle makes in a given time, under the influence of the earth's magnetism, is very much lessened by the proximity of certain metallic masses, and especially of copper, which may reduce the number

in a given time from 300 to 4. This observation led Arago in 1825 to an equally unexpected fact; that of the rotative action which a plate of copper in motion exercises on a magnet.

This phenomenon may be shown by means of the apparatus represented in fig. 676. It consists of a copper disc, M, moveable about a vertical axis. On this axis is a sheave, B, round which is coiled an endless cord passing also round the sheave A. By turning this with the hand, the disc M may be rotated with great rapidity. Above the disc is a glass plate, on which is a small pivot supporting a magnetic needle, *ab*. If the disc be now moved with a slow and uniform velocity, the needle is deflected in the direction of the motion, and stops at an angle of from 20° to 30° with the direction of the magnetic meridian, according to the velocity of the rotation of the disc. But if this velocity increases, the needle is ultimately deflected more than 90°; it is then carried along, describes an entire revolution, and follows the motion of the disc until this stops.

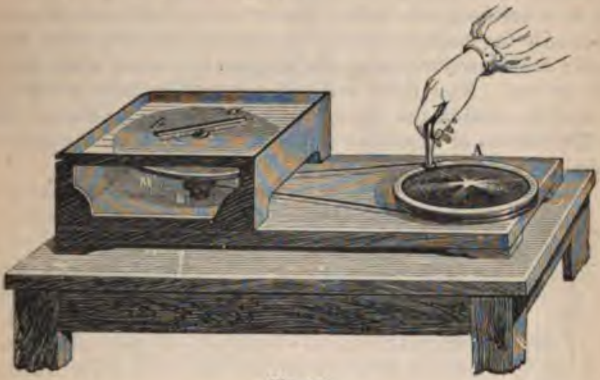


Fig. 676.

Babbage and Herschel modified Arago's experiment by causing a horseshoe magnet placed vertically to rotate below a copper disc suspended on silk threads without torsion; the disc rotated in the same direction as the magnets.

The effect decreases with the distance of the disc, and varies with its nature. The maximum effect is produced with metals; with wood, glass, water, etc. it disappears. Babbage and Herschel have found that representing this action on copper at 100, the action on other metals is as follows: zinc 95, tin 46, lead 25, antimony 9, bismuth 2. Lastly, the effect is enfeebled if the disc presents breaks in the continuity, especially in the direction of the radii; but the same physicists have observed, that it virtually regains the same intensity if these breaks have been soldered with any metal.

Faraday made an experiment the reverse of Arago's first observation; since the presence of a metal at rest stops the oscillations of a magnetic needle, the neighbourhood of a magnet at rest ought to stop the motion of a rotating mass of metal. Faraday suspended a cube of copper to a twisted thread, which was placed between the poles of a powerful electromagnet. When the thread was left to itself, it began to spin round with great velocity, but stopped the moment a powerful current passed through the electromagnet.

Faraday was the first to give an explanation of all these phenomena of magnetism by rotation. They depend on the circumstance that a magnet or a solenoid can induce currents in a solid mass of metal. In the above case the magnet induces currents in the disc, when the latter is rotated; and conversely when the magnet is rotated while the disc is primarily at rest. Now these induced currents by their electrodynamic action tend to destroy the motion which gave rise to them; they are simple illustrations of Lenz's law; they act just in the same way as friction would do.

i. For instance, let AB (fig. 677) be a needle oscillating over a copper disc, and suppose that in one of its oscillations it goes in the direction of the arrows from N to M. In approaching the point M, for instance, it develops there a current in the opposite direction, and which therefore repels it; in moving away from N it produces currents which are of the same kind, and which therefore attract, and both these actions concur in bringing it to rest.

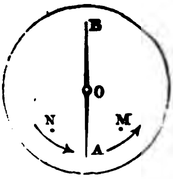


Fig. 677.

ii. Suppose the metallic mass turns from N towards M, and that the magnet is fixed; the magnet will repel by induction points such as N which are approaching A, and will attract M which is moving away; hence the motion of the metal stops, as in Faraday's experiment.

iii. If in Arago's experiment the disc is moving from N to M; N approaches A and repels it, while M moving away attracts it; hence the needle moves in the same direction as the disc.

If this explanation is true, all circumstances which favour induction will increase the dynamic reaction; and those which diminish the former will also lessen the latter. We know that induction is greater in good conductors, and that it does not take place in insulating substances; but we have seen that the needle is moved with a force which is less, the less the conducting powers of the disc, and it is not moved when the disc is of glass. Dove has found that there is no induction on a tube split lengthwise in which a coil is introduced.

In order to bring the oscillations of the needle of a galvanometer more quickly to rest, the wire is coiled upon a copper frame. Such an arrangement is called a *damper*, and in practice it is frequently used.

826. **Induction by the action of the earth.**—Faraday discovered that terrestrial magnetism can develope induced currents in metallic bodies in motion, acting like a powerful magnet placed in the interior of he earth in the direction of the dipping needle, or, according to the heory of Ampère, like a series of electrical currents directed from east to west parallel to the magnetic equator. He first proved this by placing

ong helix of copper wire covered with silk in the plane of the magnetic
ridian parallel to the dipping needle ; by turning this helix 180° round
axis perpendicular to its length in its middle, he observed that at each
n a galvanometer connected with the two ends of the helix was de-
ted. The apparatus depicted in fig. 678, and known as *Delezenne's*

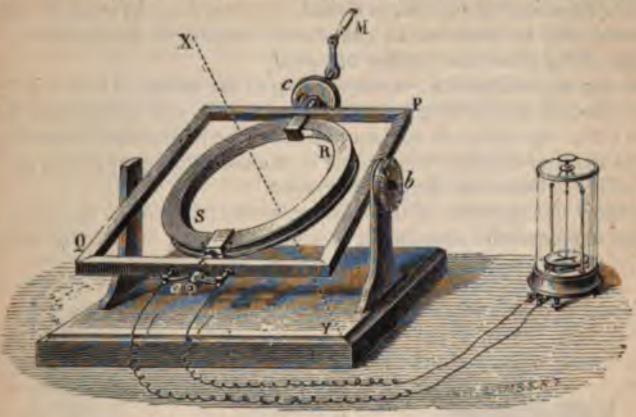


Fig. 678.

cle, serves for showing the existence of terrestrial induced currents. It
isists of a wooden ring, RS, about two feet in diameter, fixed to an axis
about which it can be turned by means of a handle, M. The axis *oi* is
elf fixed in a frame, PQ, moveable about a horizontal axis. By needles
ed to these two axes the inclination towards the horizon of the frame,
), and therefore of the axis *oa*, is indicated on a dial, *b*, while a second
l, *c*, gives the angular displacement of the ring. This ring has a groove
which is coiled a large quantity of insulated copper wire. The two ends
the wire terminate in a *commutator* analogous to that in Clarke's appa-
us (832), the object of which is to pass the current always in the same
ise, although its direction, SR, changes at each semi-revolution of the
g. On each of the rings of the commutator are two brass plates,
ich successively transmit the current to two wires in contact with the
lvanometer. The axis *oa* being in the magnetic meridian, and the ring
at right angles to the direction XY of the dipping needle, if it is
wly rotated the needle of the galvanometer is deflected, and by its
lection indicates in the wire coiled on the ring, an induced current
ose intensity increases until it has been turned through 90°; the devia-
then decreases, and is zero when the ring has made a semi-revolu-
. If the rotation continues, the current reappears, but in a contrary
ction, and attains a second maximum at 270°; becoming null again
r a complete turn. When the axis *oa* is parallel to the dip there is no
rent.

27. **Induction of a current on itself. Extra current.**—If a closed
uit traversed by a voltaic current be opened, a scarcely perceptible

spark is obtained, if the wire joining the two poles be short. Further, if the observer himself form part of the circuit by holding a pole in each hand, no shock is perceived unless the current is very intense. If, on the contrary, the wire is long, and especially if it makes a great number of turns, so as to form a bobbin with very close folds, the spark, which is inappreciable when the current is closed, acquires a great intensity when it is opened, and an observer in the circuit receives a shock which is the stronger the greater the number of turns.

Faraday has referred this strengthening of the current when it is broken to an inductive action which the current in each coil exerts upon the adjacent coils: an action in virtue of which there is produced in the bobbin a direct induced current—that is, one in the same direction as the principal one. This is known as the *extra current*.

To show the existence of this current, at the moment of opening, Faraday has arranged the experiment as seen in fig. 679. Two wires from the poles of a battery are connected with two binding screws, D and F, with which are also connected the two ends of a bobbin, B, with a long fine wire which offers therefore a great resistance. On the path of the wires at the points A and C are two other wires, which are connected with a galvanometer, G. Hence the current from the pole E branches at A into two currents, one which traverses the galvanometer, the other the bobbin, and both joining the negative pole E′.

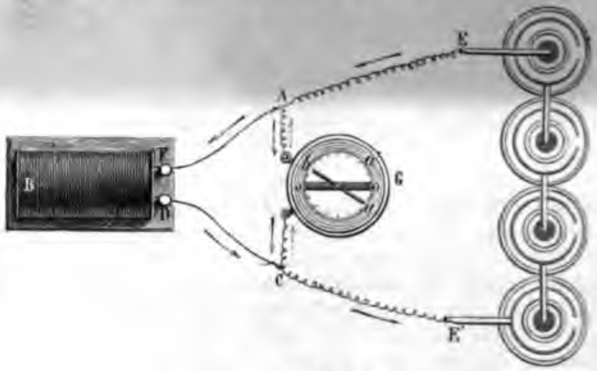


Fig. 679.

The needle of the galvanometer being then deflected by the current which goes from A to C, it is brought back to zero, and kept there by an obstacle which prevents it from turning in the direction G*a*, but leaves it free in the opposite direction. On breaking contact at E, it is seen that the moment the circuit is open the needle is deflected in the direction G*a*′; showing a current contrary to that which passed during the existence of the current—that is, showing a current from C to A. But the battery current having ceased, the only remaining one is the current AFBDCA; and since in the part CA the current goes from C to A, it nust traverse the entire circuit in the direction AFBDC—that is, the same s the principal current. This current, which thus appears when the ircuit is opened, is the *extra current.*

828. **Extra current on opening and on closing.**—The coils of the piral act inductively on each other, not merely on opening, but also on losing the current. Here, in accordance with the general law of inducion, each spire acting on each succeeding one induces a current in the opposite direction to its own—that is, an inverse current; this, which is the *extra current on closing*, or the *inverse extra current*, being of contrary direction to the principal one, diminishes its intensity, and lessens or suppresses the spark on closing.

When, however, the current is opened, each spire then acts inductively on each succeeding one, producing a current in the same direction as its own, and which therefore greatly heightens the intensity of the principal current. This is the extra current on opening, or *direct extra current.*

To observe the direct extra current, the conductor on which its effect is to be traced may be introduced into the circuit, by being connected in any suitable manner with the binding screws A and C in the place of the galvanometer.

It can thus be shown that the direct extra current gives violent shocks, bright sparks, decomposes water, melts platinum wire, and magnetises steel needles. Abria has found that the intensity of the extra current is about 0·72 of the principal current. The shock produced by the current may be tried by attaching the ends of the wire to two files, which are held in the hands. On moving the point of one file over the teeth of the other a series of shocks is obtained, due to the alternate opening and closing of the current.

The above effects acquire greater intensity when a bar of soft iron is introduced into the bobbin, or, what is the same thing, when the current is passed through the bobbin of an electromagnet; and still more is this the case if the core, instead of being massive, consists of a bundle of straight wires. Faraday explains this strengthening action of soft iron as follows: If inside the spiral there is an iron bar, when on opening the circuit the principal current disappears, the magnetism which it evokes in the bar disappears too; but the disappearance of this magnetism acts like the disappearance of the electrical current, and the disappearing magnetism induces a current in the same direction as the disappearing principal current, the effect of which is thus heightened.

In the experiments just described the effects of the two extra currents accompany those of the principal current. Edlund has devised an ingenious arrangement of apparatus by which the action of the principal current on the measuring instruments can be completely avoided, so that only that of the extra current remains. In this way he has arrived at the following laws:

i. *The intensity of the currents used being the same, the extra currents obtained on opening and closing have the same electromotive force.*

ii. *The electromotive force of the extra current is proportional to the intensity of the primary current.*

829. **Induced currents of different orders.**—Spite of their instantaneous character, induced currents can themselves, by their action on closed circuits, give rise to new induced currents, these again to others, and so on, producing *induced currents of different orders.*

These currents, discovered by Henry, may be obtained by causing to act on each other a series of bobbins, each formed of a copper wire covered with silk, and coiled spirally in one plane, like that represented in the plate A, in fig. 673. The currents thus produced are alternately in opposite directions, and their intensity decreases in proportion as they are of a higher order.

830. **Properties of induced currents.**—Notwithstanding their instantaneous character, it appears from the preceding experiments that induced currents have all the properties of ordinary currents. They produce violent physiological, luminous, calorific, and chemical effects, and finally give rise to new induced currents. They also deflect the magnetic needle, and magnetised steel bars when they are passed through a copper wire coiled in a helix round the bars.

The intensity of the shock produced by induced currents renders their effects comparable to those of electricity in a state of tension.

The direct induced current and the inverse induced current have been compared as to three of their actions: the violence of the shock, the deflection of the galvanometer, and the magnetising action on steel bars. In these respects they differ greatly: they are about equal in their action on the galvanometer; but while the shock of the direct current is very powerful, that of the inverse current is scarcely perceptible. The same difference prevails with reference to the magnetising force. The direct current magnetises to saturation, while the inverse current does not magnetise.

831. **Laws of induced currents.**—In his special treatise on induction, Matteucci has deduced from his own researches, and from those of Faraday, Lenz, Dove, Abria, Weber, Marianini, and Felici, the following laws in reference to induced currents:

i. *The intensity of induced currents is proportional to that of the inducing currents.*

ii. *This intensity is proportional to the product of the length of the inducing and induced currents.*

iii. *The electromotive force developed by a given quantity of electricity is the same whatever be the nature, section, or shape of the inducing circuit.*

iv. *The electromotive force developed by the induction of a current on any given conducting circuit is independent of the nature of the conductor.*

v. *The development of induction is independent of the nature of the insulating body interposed between the induced and inducing circuit.*

This latter law is in disaccord with the experiments of Faraday, on the induction of statical electricity (687).

APPARATUS FOUNDED ON INDUCTION.

832. **Magneto-electrical apparatus.**—After the discovery of magneto-ectrical induction, several attempts were made to produce an uninterpted series of sparks by means of a magnet. Apparatus for this purpose ere devised by Pixii and Ritchie, and subsequently by Saxton, ttingshausen, and Clarke. Fig. 680 represents that invented by Clarke. consists of a powerful horse-shoe magnetic battery, A, fixed against a ertical wooden support. In front of this there are two bobbins, BB′, noveable round a horizontal axis. These bobbins are coiled on two ylinders of soft iron joined at one end by a plate of soft iron, V, and at he other by a similar plate of brass. These two plates are fixed on a opper axis, terminated at one end by a commutator, *qi*, and at the other y a pulley, which is moved by an endless band passing round a large heel, which is turned by a handle.

Fig. 681.

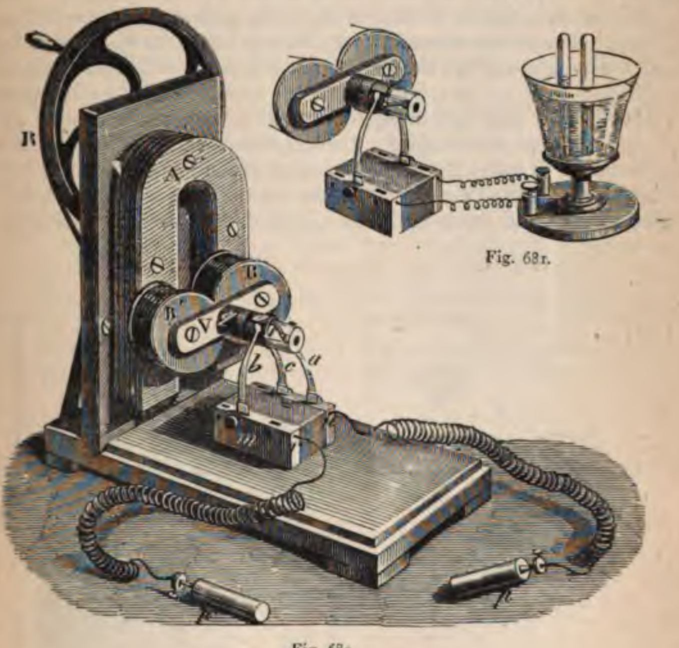


Fig. 680.

Each bobbin consists of about 1,500 turns of very fine copper wire overed with silk. One end of the wire of the bobbin B is connected on he axis of rotation with one end of the wire of the bobbin B′, and the wo other ends of these wires terminate in a copper ferrule or washer, *q*, hich is fixed to the axis, but is insulated by a cylindrical envelope of ivory. In order that in each wire the induced current may be in the sam direction, it is coiled on the two bobbins in different directions—that is one is right-handed, the other left-handed.

When now the electromagnet turns, its two branches become alternately magnetised in contrary directions under the influence of th magnet A, and in each wire an induced current is produced, the directio of which changes at each half turn.

Let us follow one of the bobbins—B, for instance—while it makes a complete revolution in front of the poles *a* and *b* of the magnet; calling th poles of the electromagnet successively *a'* and *b'*. Let us further conside the latter when it passes in front of the north pole of the magnetic batter (fig. 682). The iron has then a south pole in which, as we know, the Ampèrian currents move like the hands of a watch. The contrary seems t be represented by fig. 682, but it must be remembered that the bobbin are seen here as they are in fig. 680; and hence, when viewed at th end which grazes the magnet, the Ampèrian currents seem to tur like the hands of a watch. These currents act inductively on the wire o the bobbin, producing a current in the same direction (822, iii.), for th bobbin moves away from the pole *a*, its soft iron is demagnetised, an

Fig. 682.

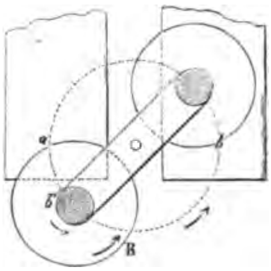
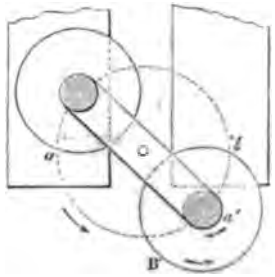


Fig. 683.



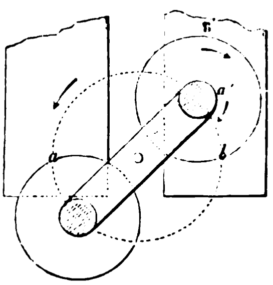


Fig. 684.

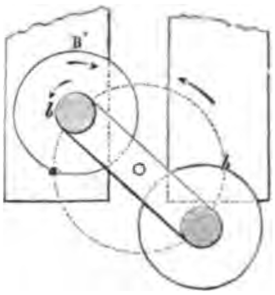


Fig. 685.

the Ampèrian currents cease (822). The intensity of the induced current in the bobbin decreases, until the right line joining the axes of the

› bobbins is perpendicular to that which joins the poles *a* and *b* of the r. There is now no magnetism in the bar, but quickly approaching the le *b*, its soft iron is then magnetised in the opposite direction—that is, it comes a north pole (fig. 683). The Ampèrian currents are then in the ection of the arrow *a′*; and as they are commencing, they develope in wire of the bobbin an inverse current (822), which is in the same ection as that developed in the first quarter of the revolution. More-er, this second current adds itself to the first, for while the bobbin ves away from *a*, it approaches *b*. Hence, during the lower half olution from *a* to *b*, the wire was successively traversed by two induced rents in the same direction, and if the rotatory motion is sufficiently id, we might admit during this half revolution the existence of a single rent of the wire.

The same reasoning applied to the figures 684 and 685 will show that ing the upper half revolution the wire of the bobbin B is still traversed a single current, but in the opposite direction to that of the lower half olution. What has been said about the bobbin B applies obviously to bobbin B′; yet as one of these is right-handed and the other left-nded, during each upper or lower half revolution the currents are istantly in the same direction in the two bobbins. At each successive lf revolution they both change, but are in the same direction as regards h other; the term direction having here reference to figs. 682–685.

33. **Commutator.**—The object of this apparatus (fig. 686), of which 687 is a section, is to bring the two alternating currents always in the

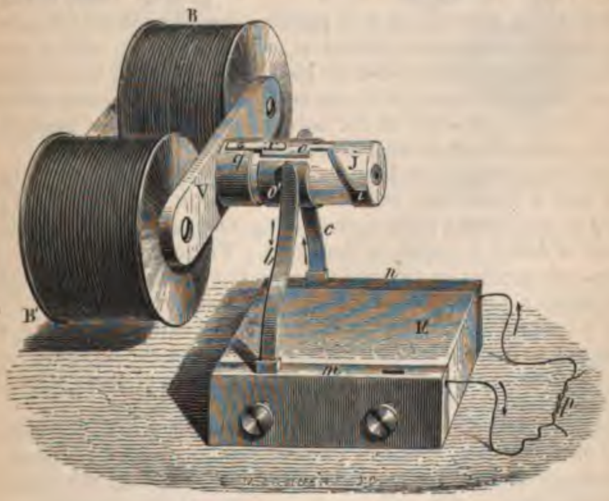


Fig. 686.

me direction. It consists of an insulating cylinder of ivory or ebony, J, the axis of which is a copper cylinder, K, of smaller diameter, fixed to the armature V, and turning with the bobbins. On the ivory cylinder is first a brass ferrule, *q*, and in front of it two half ferrules, *o* and *o′*, also of brass and completely insulated from one another. The half ferrule *o′* is connected with the ferrule *q* by a tongue, *x*. On the sides of a block of wood, M, there are two brass plates, *m*, *n*, on which are screwed two elastic springs, *b* and *c*, which press successively on the half ferrules *o* and *o′*, when rotation takes place.

We have already seen that the two ends of the wire of the bobbin, those in the same direction with respect to the currents passing through them at any time, which will be found to be those farthest away from the armature V, terminate in the metallic axis *k*, and therefore on the half ferrule *o′*; while the other two ends, both in the same direction with respect to the current, are joined to the ferrule *q*, and therefore to the half ferrule *o*. It follows that the pieces *o o′* are constantly poles of alternating currents which are developed in the bobbins; and as these are alternately in contrary directions, the pieces *o* and *o′* are alternately positive and negative. Now, taking the case in which the half ferrule *o′* is positive, the current descends by the spring *b*, follows the plate *m*, arrives at *n* by the joining wire *p*, ascends in *c*, and is closed by contact with the piece *o*; then, when in consequence of rotation *o* takes the place of *o′*, the current retains the same direction; for, as it is then reversed in the bobbins, *o* has become positive and *o′* negative, and so forth as long as the bobbin is turned.

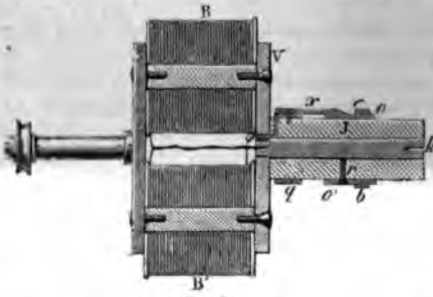


Fig. 687.

With the two springs *b* and *c* alone, the opposite currents from the two pieces *o* and *o′* could not unite when *m* and *n* are not joined; this is effected by means of a third spring, *a* (fig. 680), and of two appendices, *i*, only one of which is visible in the figure. These two pieces are insulated from one another on an ivory cylinder, but communicate respectively with the pieces *o* and *o′*. As often as the spring *a* touches one of these pieces it is connected with the spring *b*, and the current is closed, for it passes from *b* to *a*, and then reaches the spring *c* by the plate *n*. On the contrary, as long as the spring *a* does not touch one of these appendices the current is broken.

For physiological effects the use of the spring *a* greatly increases the intensity of the shocks. For this purpose two long spirals of copper wire with handles, *p* and *p′*, are fixed at *n* and *m*. Holding the handles in the hands so long as the spring *a* does not touch the appendices *i*, the current passes through the body of the experimenter, but without appreciable effect; while each time that the plate *a* touches one of the appendices *i*, the current, as we have seen above, is closed by the pieces *b*, *a*, and *c*, and ceasing then to pass through the wires *np*, *mp'*, there is produced in this and through the body a direct extra-current which produces a violent shock.

This is renewed at each semi-revolution of the electromagnet, and its intensity increases with the velocity of the rotation. The muscles contract with such force that they do not obey the will, and the two hands cannot be detached. With a well-constructed apparatus of large dimensions a continuance of the shock is unendurable; the person receiving it is prostrated, rolls on the ground, and is soon completely at the mercy of the operator.

All the effects of voltaic currents may be produced by the induced currents of Clarke's machine. Fig. 681 shows how the apparatus is to be arranged for the decomposition of water. The spring *a* is suppressed, the current being closed by the two wires which represent the electrodes.

For physiological and chemical effects the wire rolled on the bobbins is fine, and each about 500 to 600 yards in length. For physical effects, on the contrary, the wire is thick, and there are about 25 to 35 yards on each bobbin. Figs. 688 and 689 represent the arrangement of the bobbins and the commutator in each case. The first represents the inflammation of ether, and the second the incandescence of a metallic wire, *o*, in which the current from the plate *a*, to the plate *c*, always passes in the same direction.

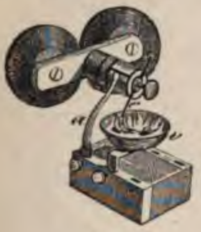


Fig. 688.

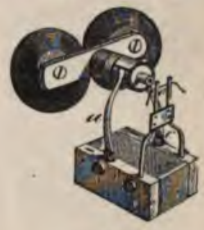


Fig. 689.

Pixii's and Saxton's electromagnetic machine differs from Clarke's in having the electromagnet fixed while the magnet rotates.

Wheatstone has recently devised a compendious form of the magneto-electrical machine, for the purpose of using the induced spark in firing mines (730).

834. **Magneto-electrical machine.**—The principle of Clarke's apparatus has received in the last few years a remarkable extension in large magneto-electrical machines, by means of which mechanical work is transformed into powerful electric currents by the inductive action of magnets on bobbins in motion.

The first machine of this kind was invented by Nollet, in Brussels, in 1850; this has been greatly improved by Van Malderen, who has also applied it to electrical illumination.

This machine is represented in fig. 690, as it stands in a workshop at the Hôtel des Invalides, in Paris, where it was constructed. One of these machines was exhibited in the International Exhibition of 1862. It consists of a cast-iron frame, 5½ feet in height, on the circumference of

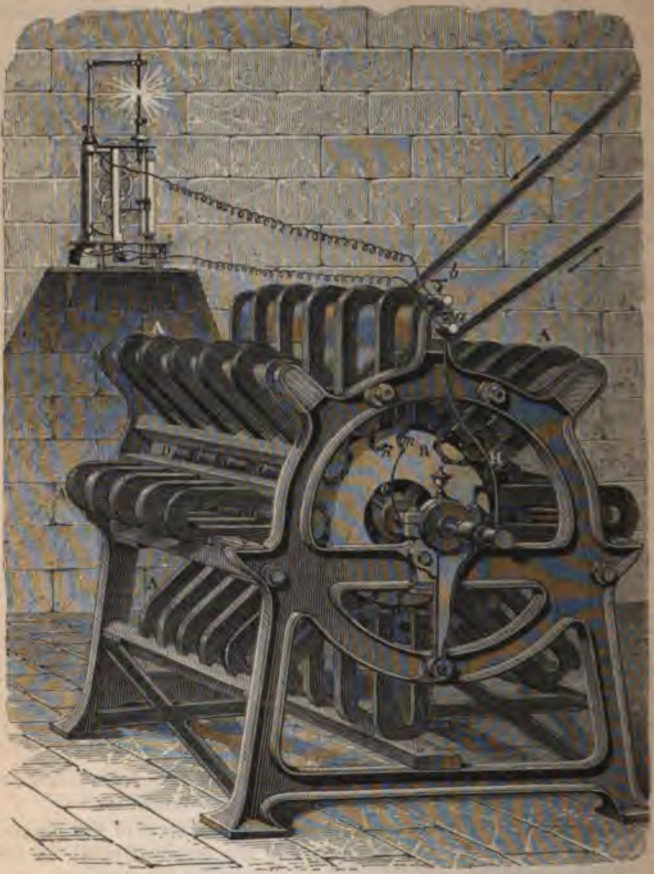


Fig. 690.

which eight series of five powerful horse-shoe-magnetic batteries, A, A, A – are arranged in a parallel order on wooden cross-pieces. These batteries, each of which can support from 120 to 130 pounds, are so arranged that, if they are considered either parallel to the axis of the frame, or in a plane perpendicular to this axis, opposite poles always face one another. In each series the outside batteries consist of three magnetised plates, while the three middle ones have six plates, because they act by both faces, while the first only acts by one.

On a horizontal iron axis going from one end to the other of the frame four bronze wheels are fixed, each corresponding to the intervals between the magnetic batteries of two vertical series. There are 16 bobbins on the circumference of each of these—that is, as many as there are magnetic poles in each vertical series of magnets. These bobbins, represented in fig. 692, differ from those of Clarke's apparatus in having, instead of a single wire, 12 wires each, 11½ yards in length, by which the resistance is diminished. The coils of these bobbins are insulated by means of bitumen dissolved in oil of turpentine. These are not rolled upon solid cylinders of iron, but on two iron tubes, slit longitudinally; this device renders the magnetisation and demagnetisation more rapid when the bobbins pass in front of the poles of the magnet. Further, the discs of copper which terminate the bobbins are divided in the direction of the radius, in order to prevent the formation of induced currents in these discs. The four wheels being respectively provided with 16 bobbins each, there are altogether 64 bobbins arranged in 16 horizontal series of four, as seen at D, on the left of the frame. The length of the wire on each bobbin being 12 times 11½ yards, or 138 yards, the total length in the whole apparatus is 64 times 138 yards, or 8,832 yards.

The wires are coiled on all the bobbins in the same direction, and not only on the same wheel, but on all four, all wires are connected with one another. For this purpose the bobbins are joined, as shown in fig. 691; on the first wheel the twelve wires of the first bobbin, *x*, are connected on a piece of mahogany fixed on the front face of the wheel with a plate of copper, *m*, connected by a wire, O, with the centre of the axis which supports the wheels. At the other end, on the other face of the wheel, the same wires are soldered to a plate indicated by a dotted line which connects them with the bobbin *y*; from this they are connected with the bobbin *z* by a plate, *i*, and so on, for the bobbins *t*, *u* . . . up to the last, *v*. The wires of this bobbin terminate in a plate, *n*, which traverses the first wheel, and is soldered to the wires of the first bobbin of the next wheel, on which the same series of connections is repeated; these wires pass to the third wheel, thence to the fourth, and so on, to the end of the axis.

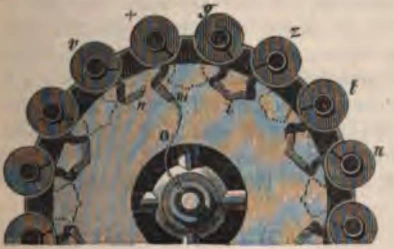


Fig. 691.

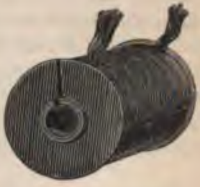


Fig. 692.

The bobbins being thus arranged, one after another, like the elements of a battery connected in a series (759), the electricity has high tension. But the bobbins may also be arranged by connecting the plates alternately, not with each other, but with two metal rings in such a manner that all the ends of the same name are connected with the same ring. Each of these rings is then a pole, and this arrangement may be used where a high degree of tension is not required.

From these explanations it will be easy to understand the manner in which electricity is produced and propagated in this apparatus. An endless band receiving its motion from a steam engine passes round a pulley fixed at the end of the axis which supports the wheels and the bobbins, and moves the whole system with any desired rapidity. Experience has shown that to obtain the greatest degree of light, the most suitable velocity is 235 revolutions in a minute. During this rotation, if we at first consider a single bobbin, the tube of soft iron on which it is coiled, in passing in front of the poles of the magnet, undergoes at its two ends an opposite induction, the effects of which are added, but change from one pole to another. As these tubes, during one rotation, pass successively in front of sixteen poles alternately of different names, they are magnetised eight times in one direction, and eight times in the opposite direction. In the same time there are thus produced in the bobbin eight direct induced currents and eight inverse induced currents; in all, sixteen currents in each revolution. With a velocity of 235 turns in a minute, the number of currents in the same time is $235 \times 16 = 3760$ alternately in opposite directions. The same phenomenon is produced with each of the 64 bobbins; but as they are all coiled in the same direction, and are connected with each other, their effects accumulate, and there is the same number of currents, but they are more intense.

To utilise these currents in producing an intense electric light, the communications are made as shown in fig. 693. On the posterior side the last bobbin, x', of the fourth wheel terminates by a wire, G, on the axis MN, which supports the wheels: the current is thus conducted to the axis, and thence over all the machine, so that it can be taken from any desired point. In the front the first bobbin, x, of the first wheel communicates by the wire O, not with the axis itself, but with a steel

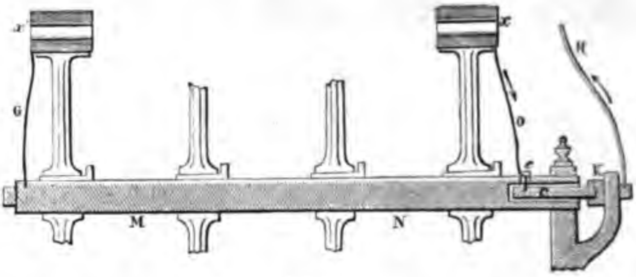


Fig. 693.

cylinder, *c*, fitted in the axis, from which, however, it is insulated by an ivory collar. The screw *e*, to which the wire O is attached, is likewise insulated by a piece of ivory. From the cylinder *c* the current passes to a fixed metallic piece, K, from which it passes to the wire H, which transmits it to the binding screw *a* of fig. 690. The binding screw *b* communicates with the framework, and therefore with the wire of the last bobbin, x' (fig. 693). From the two binding screws *a* and *b* the current is conducted by means of two copper wires to two charcoals, the distance of which is regulated by means of an apparatus analogous in principle to that already described (767).

In this machine the currents are not rectified so as to be in the same direction; hence each carbon is alternately positive and negative, and in fact they are consumed with equal rapidity. Experiment has shown that, when these currents are applied to produce the electric light, it is not necessary they should be in the same direction; but when they are to be used for electrometallurgy, or for magnetising, they must be rectified, which is effected by means of a suitable commutator.

The light produced by the magneto-electrical machine is very intense; with a machine of four wheels the light obtained is equal to that of 150 Carcel lamps. A machine of six wheels gives a light equal to 200 Carcel lamps.

Serrin has constructed a new regulator for this light, which, like the older ones, brings the charcoals together in proportion as they become used; and further removes them when they are in contact. It contains no clockwork motion, and is worked by the weight of one of its pieces.

This light, which requires no other expenditure than that of a single horse-power to turn the coils when there are not more than four of them, is advantageously used for signalling by night on large vessels, and for lighthouses.

One of these, constructed by Holmes, is now in use at the South Foreland lighthouse.

835. **Siemens' armature.**— Siemens has devised an armature or bobbin for magneto-electrical machines, in which the insulated wire is wound longitudinally on the core, instead of transversely, as is usually the case.

It consists of a soft iron cylinder, AB (fig. 694), from one foot to three feet in length, according to circumstances.

A deep groove is cut on the outer length of this core and on the ends, in which is coiled the insulated wire as in a multiplier. To the two ends of the cylinder brass discs, E and D, are secured. With E is connected a commutator, C, consisting of two pieces of steel insulated from each other and connected respectively with the two ends of the wire. On the other

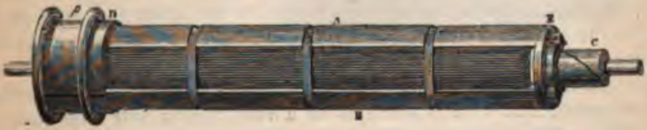


Fig. 694.

disc is a pulley, round which passes a cord, so that the bobbin moves very rapidly on the two pivots.

When a voltaic current circulates in the wire, the two cylindrical segments, A and B, are immediately magnetised, one with one polarity and the other with the opposite. On the other hand, if, instead of passing a voltaic current through the wire of the bobbin, the bobbin itself be made to rotate rapidly between the opposite poles of magnetised masses, as the segments A and B become alternately magnetised and demagnetised, their induction produces in the wire a series of currents alternately positive and negative, as in Clarke's apparatus (832). When these currents are collected in a commutator which adjusts them—that is, sends all the positive currents on one spring and all the negative on another—these springs become electrodes, from one of which positive electricity starts and from the other negative. If these springs are connected by a conductor, the same effects are obtained as when the two poles of a battery are united.

Siemens has constructed magneto-electrical machines in which this armature is utilised. It has the great advantage that a large number of small magnets may be used instead of one large one. As, weight for weight, the former possesses greater magnetic force than the latter, they can be made more economically. And as the armature is always very near the magnets, it receives greater momentum, and is more rapidly changed.

836. **Wild's magneto-electrical machine.**—Mr. Wild has recently constructed a magneto-electrical machine, in which Siemens' armature is used along with a new principle—that of the multiplication of the current. Instead of utilising directly the current produced by the induction of a magnet, Mr. Wild passes it into a strong electromagnet, and by the induction of this latter a more energetic current is obtained.

This machine consists first of a battery of 12 to 16 magnets, each of which weighs about 3 pounds, and can support about 20 pounds. Between the poles of the magnets two soft iron keepers, CC, are arranged, separated by a brass plate, O. These three pieces are joined by bolts, and the whole compound keeper is perforated longitudinally by a cylindrical cavity, in which works a Siemens' armature, *n*, about 2 inches in diameter. The wire of this armature terminates in a commutator, which leads the positive and negative currents to two binding screws, *a* and *b*. This commutator is represented on a larger scale in fig. 697. At the other end is a pulley by which the armature can be turned at the rate of 25 turns in a second. The wire on the armature is 20 yards long.

Below the support for the magnets and their armatures are two large electromagnets, BB. Each consists of a rectangular soft iron plate, 36 inches in length by 26 in breadth and 1¼ inch thick, on which are coiled about 1,600 feet of insulated copper wire. The wires of these electromagnets are joined at one end, so as to form a single circuit of 3,200 feet. One of the other ends is connected with the binding screw *a* and the other with *b*. At the top the two plates are joined by a transverse plate of iron so as to form a single electromagnet.

At the bottom of the electromagnets BB are two iron armatures separated by a brass plate, O, and in the entire length is a cylindrical channel in which works a Siemens' armature as above: this armature, however, is above a yard in length, nearly 6 inches in diameter, and its wire is 100 feet long. The ends are connected with a commutator, from which the adjusted currents pass to two wires, *r* and *s*. The armature *m* is rotated at the rate of 1,700 turns in a minute.

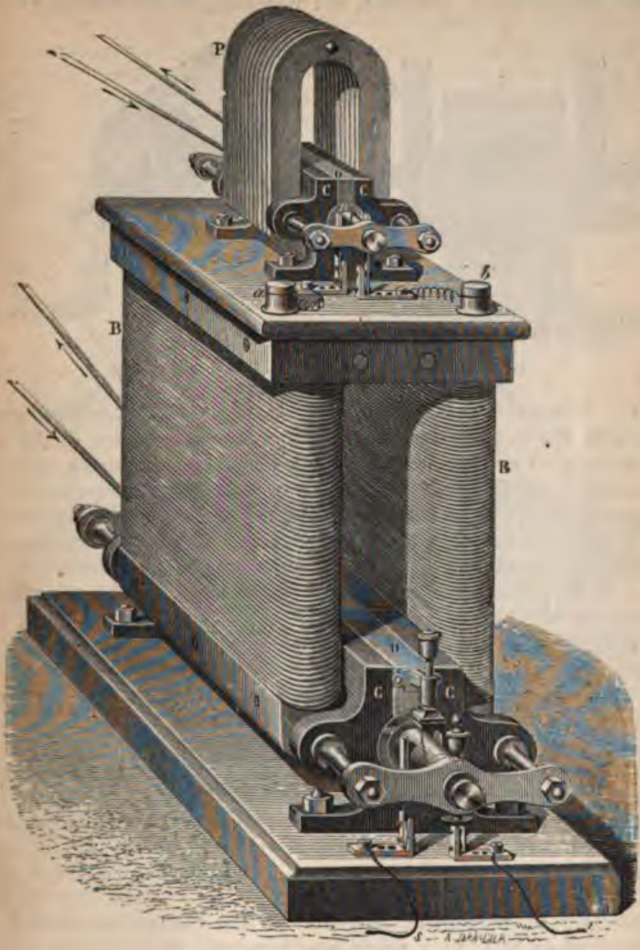


Fig. 695.

Fig. 696 shows on a larger scale a cross section of the bobbin *m* of the armatures CC and of the plates AA, on which is coiled the wire of the electromagnets BB'.

These details being premised, the following is the working of the

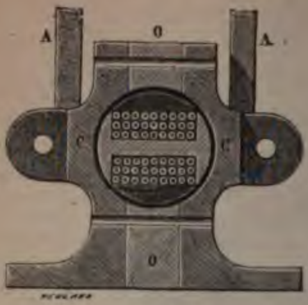


Fig. 696.

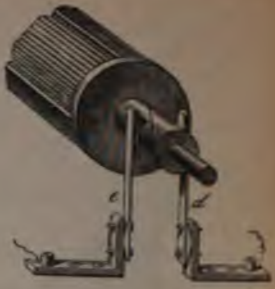


Fig. 697.

machine. When the armatures n and m are rotated by means of a steam engine with the velocity mentioned, the magnets produce in the first armature induced currents, which, adjusted by the commutator, pass into the electromagnet BB, and magnetise it. But as these impart to the lower armatures CC opposite polarities, the induction of these latter produces in the armature m a series of positive and negative currents far more powerful than those of the upper armature; so that when these are adjusted by a commutator and directed by the wires r and s, very powerful effects are obtained.

These effects are still further intensified if, as Mr. Wild has done, the adjusted current of the armature m is passed into a second electric magnet, whose armatures surround a third and larger Siemens' armature turning with the two others. A current is thus obtained which melts an iron wire a foot long and more than 2 inches in diameter.

837. **Ladd's dynamomagnetic machine.**—Mr. Ladd, philosophical instrument maker, in Beak Street, Regent Street, has invented a very remarkable dynamomagnetic machine. It consists of two Siemens' armatures, rotating with great velocity, and of two iron plates, AA (fig. 698), surrounded by an insulated copper wire. Ladd's machine differs from that of Wild in the following respects:

i. There are no permanent magnets: ii. the electromagnets BB are not joined so as to form a single electromagnet, but are two distinct electromagnets, each having at the end two hollow cylinders, CC', in which are fitted two Siemens' armatures, m and n; the current of the armature n passing round the electromagnets reverts to itself. This reaction of the current upon itself is an essential feature of the machine; it is an application of a principle announced simultaneously by Mr. Wheatstone and by Mr. Siemens. The wire of the armature m is independent, and passes into the apparatus which is to utilise the current—for instance, two carbon points, D.

The machine being thus arranged, if a voltaic current be passed once for all through the electromagnets BB, it magnetises the plates AA and their keepers, which by their reciprocal action retain a quantity of remanent magnetism sufficient to work the machine. If, then, the armatures m and n be rotated by means of two bands passing round a common drum, the magnetism of the hollow cylinders CC′ acting upon the armature n, excites induction currents, which, adjusted by a commutator, pass round the electromagnets BB, and more strongly magnetise the cylinders or *shoes* CC′. These in their turn reacting more powerfully on the armature n, strengthen the current ; we thus see that n and B continually and mutually strengthen each other as the velocity of the rotation ncreases. Hence as the iron of the armature m becomes more and more strongly magnetised under the influence of the electromagnets BB, a gradually more intense induced current is developed in this armature, which is directed, commutated or not, according to the use for which it is designed.

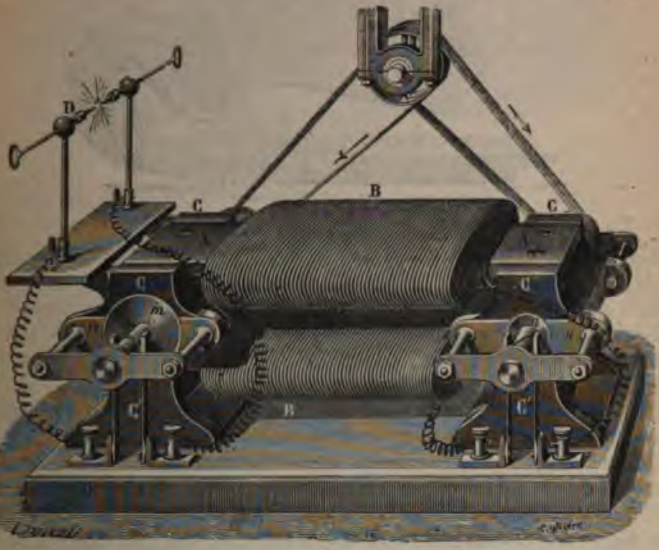


Fig. 698.

In a machine which Mr. Ladd exhibited at the Paris Exhibition of 1867 he plates AA were only 24 inches in length by 12 inches in width. With hese small dimensions the current is equal to 25 to 30 Bunsen's cells. It an work the electric light and keep incandescent a platinum wire a metre n length and 0·5mm. in diameter.

The above form of the machine is worked by steam power. Mr. Ladd as devised a more compact form, which may be worked by hand. This s represented in fig. 699. The two armatures are fixed end to end, and he coils are wound on it at right angles to each other, as shown in the gure. The current from this can raise to white heat 18 inches of platinum wire 0·01 in. thickness, and with an inductorium containing 3 miles of secondary wire 2 in. sparks can be obtained.

Both Ladd's and Wild's machines are liable to the objection of requiring to be rotated at a rapid rate. The armatures become heated by the repeated development of induction currents. This has been remedied by Mr. Ladd, who has introduced into the shoes or hollow cylinders several apertures through which a stream of cold water is made to flow. Before they can be applied industrially, their velocity must be reduced, either by multiplying the number of Siemens' armatures or modifying their arrangement.

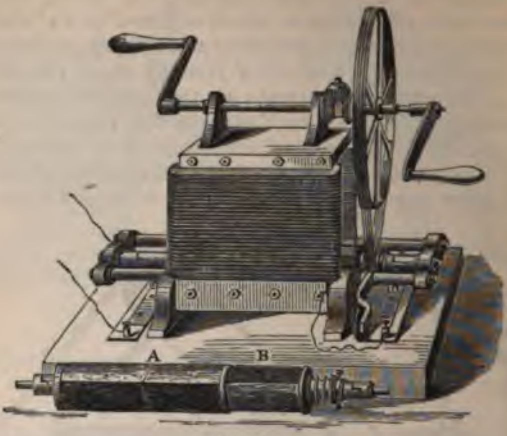


Fig. 699.

These machines furnish a remarkable instance of the transformation of mechanical force into electricity, light, and heat (269. 461).

838. **Gramme's magneto-electrical machine.**—The magneto-electrical machines which have hitherto been described are all open to the objection that they only give momentary currents, alternately positive and negative. These currents may indeed be used for lighting and for physiological purposes, but for other applications, such as for electroplating, they must be *rectified*; that is, by means of a commutator, they must be sent always in the same direction. This, however, is in all cases accompanied by a certain loss of electricity, and sparks are produced which rapidly wear away the armatures of the commutators.

These inconveniences are not met with in an apparatus invented by M. Gramme, of which fig. 700 is a representation in about ¼th of the natural size. On a base is a powerful magnetic battery, between the limbs of which an axle is rotated by means of a pulley and an endless band. On this axle, and in the same plane as the branches of the magnet, is a soft iron ring, on which are wound 35 coils of insulated copper wire, each having nearly 300 turns. In each one the wire is bent inside the ring, and is soldered to an insulated piece of brass. It is then again folded on the ring so as to form a second coil. From this it passes to a piece of brass similar to the first, and so on, forming a continuous conductor divided into 35 identical bobbins.

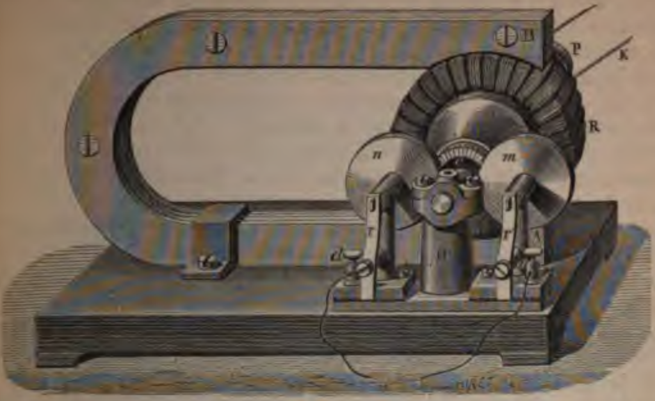


Fig. 700.

All the pieces of brass to which the copper wire is soldered are insulated from the apparatus, and form a bundle at *c* around the axis. There, on the same horizontal diameter of the ring, one part of these pieces is in contact with two brass discs, *m* and *n*, represented in fig. 701, which shows below them the bobbins and their accessories. These two discs slide on their supports in the direction of the axis, and two springs press them against the pieces *c*.

Suppose now that the ring with its coils turn from right to left in passing under the pole B of the magnet, the upper part of the ring acquires a polarity the reverse of that of the ring, and its magnetisation developes a current the inverse of the Ampèrian currents (822) in the coils which approach the pole, and direct in those which recede from it (822). Hence, if the current formed on the right near the middle part, R, of the system is positive, that developed in the opposite region is negative.

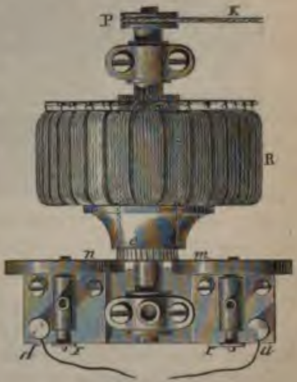


Fig. 701.

In front of the pole A a similar effect is produced, but here the polarity of A being the opposite of that of B, the inverse current from below towards R is positive, and the current on the left which is negative.

Thus there are continually two positive currents proceeding from the upper and lower coils towards the medial region R, and two negative currents directed towards the opposite sides. These currents pass thence to the corresponding pieces *c*, whence they are collected by the discs *m* and *n*, which transmit them to the two binding screws *a* and *b*. A continuous current is thus produced which is always in the same direction, *m* being the positive pole and *n* the negative pole. If the rotation is in the opposite direction, the poles are reversed.

This apparatus, though small in size—9 inches in height—is very powerful; it can decompose water and heat to redness an iron wire 20 centimetres in length and a millimeter in diameter. Its power increases with the velocity of its rotation up to a limit of 700 to 800 turns in a minute, and its effects vary according as the wire of the bobbins is thick and short or fine and long.

839. **Inductorium. Ruhmkorff's coil.**—These are arrangements for producing induced currents, in which a current is induced by the action of an electric current, whose circuit is alternately opened and closed in rapid succession. These instruments, known as *inductoriums* or *induction coils*, present considerable variety in their construction, but all consist essentially of a hollow cylinder in which is a bar of soft iron, or bundle of iron wires, with two helices coiled round it, one connected with the poles of a battery, the current of which is alternately opened and closed by a self-acting arrangement, and the other serving for the development of the induced current. By means of these apparatus, with a current of three or four Grove's cells, physical, chemical, and physiological effects are produced equal to and superior to those obtainable with electrical machines and even the most powerful Leyden batteries.

Of all the forms those constructed by Ruhmkorff are the most powerful. Fig. 702 is a representation of one, the coil of which is about 14 inches in length. The *primary* or *inducing* wire is of copper, and is about 2mm. in diameter and 40 or 50 yards in length. It is coiled directly on a cylinder of cardboard, which forms the nucleus of the apparatus, and is enclosed in an insulating cylinder of glass, or of caoutchouc. On these is coiled the secondary or induced wire, which is also of copper, and is about $\frac{1}{3}$mm. in diameter. A great point in these apparatus is the insulation. The wires are not merely insulated by being in the first case

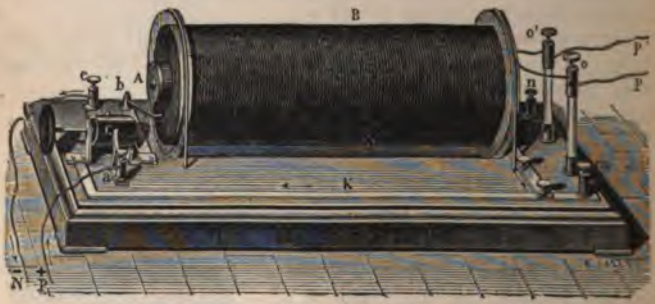


Fig. 702.

overed with silk, but each individual coil is separated from the rest by a ayer of melted shellac. The length of the secondary wire varies greatly; n some of Ruhmkorff's largest sizes it is as much as 60 miles. With hese great lengths the wire is thinner, about $\frac{1}{6}$mm. The thinner and onger the wire the greater the *tension* of the induced electricity.

The following is the working of the apparatus. The current arriving y the wire P at a binding screw, *a*, passes thence into the commutator C, to be afterwards described (fig. 704), thence by the binding screw *b* t enters the primary wire, where it acts inductively on the secondary wire; having traversed the primary wire, it emerges by the wire *s* (fig. 703). Following the direction of the arrows, it will be seen that the current ascends in the binding screw *i*, reaches an oscillating piece of iron, *o*, called the *hammer*, descends by the *anvil* *h*, and passes into a copper plate, K, which takes it to the commutator C. It goes from there to the binding screw *c*, and finally to the negative pole of the battery by the wire N.

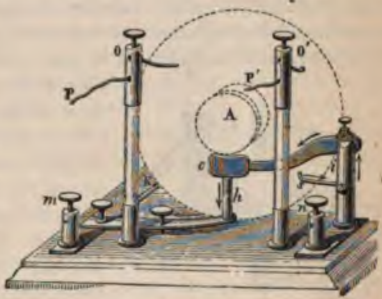


Fig. 703.

The current in the primary wire only acts inductively on the secondary wire (820), when it opens or closes, and hence must be constantly interrupted. This is effected by means of the oscillating hammer *o* (fig. 803). In the centre of the bobbin is a bundle of soft iron wires, forming together a cylinder a little longer than the bobbin, and thus projecting at the end as seen at A. When the current passes in the primary wire, this hammer *o* is attracted; but immediately, there being no contact between *o* and *h*, the current is broken, the magnetisation ceases, and the hammer falls; the current again passing, the same series of phenomena recommences, so that the hammer oscillates with great rapidity.

840. **Condenser.**—In proportion as the current passes thus intermittently n the primary wire of the bobbin, at each interruption an induced current, alternately direct and inverse, is produced in the secondary wire. But as this is perfectly insulated, the induced current acquires such an ntensity as to produce very powerful effects. Fizeau has increased this ntensity still more by interposing a condenser in the primary circuit. s constructed by Ruhmkorff for his largest apparatus, this consists of 150 heets of tinfoil about 18 inches square, so that the total surface is about 5 square yards. These sheets being joined, are fastened on two sides of band of oiled silk, which insulates them, forming thus two coatings; ey are then coiled several times round each other, another band of silk eing interposed, so that the whole can be placed below the helix in the ase of the apparatus. One of these coatings, the positive, is connected ith the binding screw *i*, which receives the current on emerging from

the bobbin; and the other, the negative, is connected with the binding screw *m*, which communicates by the plate K with the commutator C, and with the battery.

To understand the effect of the condenser, it must be observed that at each break of the inducing current an extra current is produced in the same direction, which, continuing in a certain manner, prolongs its duration. It is this extra current which produces the spark that passes at each break between the hammer and the anvil; when the current is strong this spark rapidly alters the surface of the hammer and anvil, though they are of platinum. By interposing the condenser in the inducing circuit, the extra current, instead of producing so strong a spark, darts into the condenser; the positive electricity in the coating connected with *i*, and the negative in that connected with *m*. But the opposite electricities combining quickly by the thick wire of the primary coil, by the battery and the circuit CK*m*, give rise to a current contrary to that of the battery, which instantaneously demagnetises the bundle of soft iron; the induced current is thus shorter and more intense. The binding screws *m* and *n* on the base of the apparatus are for receiving this extra current.

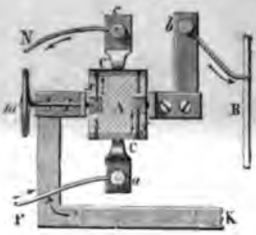


Fig. 704.

The *commutator* or *key* serves to break contact or send the current in either direction. The section in fig. 704 is entirely of brass, excepting the core A, which is ebonite; on the two sides are two brass plates, CC′. Against these press two elastic brass springs, joined to two binding screws, *a* and *c*, with which are also connected the electrodes of the battery. The current arriving at *a* ascends in C, thence by a screw *y* it attains the binding screw *b* and the bobbin; then returning by the plate K, which is connected with the hammer, the current goes to C′ by the screw *x*, descends to *c*, and rejoins the battery by the wire N. If by means of the milled head the key is turned 180 degrees, it is easy to see that exactly the opposite takes place; the current reaches the hammer by the plate K and emerges at *b*. Finally, if it is only turned through 90 degrees, the elastic plates rest on the ebonite A instead of on the plates CC′, and the current is broken.

The two wires from the bobbin at *o* and *o*′ (fig. 702) are the two ends of the secondary wire. They are connected with the thicker wires PP′, so that the current can be sent in any desired direction. With large coils the hammer cannot be used, for the surfaces become so much heated as to melt. But M. Foucault has recently invented a mercury interrupter which is free from this inconvenience, and which is an important improvement.

841. **Effects produced by Ruhmkorff's coil.**—The high degree of tension which the electricity of induction coil machines possesses has long been known, and many luminous and calorific effects have been obtained by their means. But it is only since the improvements which

Ruhmkorff has introduced into his coil, that it has been possible to utilise all the tension of induced currents, and to show that these currents possess the properties of statical as well as dynamical electricity.

Induced currents are produced in the coil at each opening and breaking of contact. But these currents are not equal either in duration or in tension. The direct current, or that on *opening*, is of shorter duration, but more tension; that of *closing* of longer duration but less tension. Hence if the two ends P and P′ of the fine wire (figs. 702 and 703) are connected, as there are two equal and contrary quantities of electricity in the wire the two currents neutralise each other. If a galvanometer is placed in the circuit, only a very feeble deflection is produced in the direction of the direct current. This is not the case if the two extremities P and P′ of the wire are separated. As the resistance of the air is then opposed to the passage of the currents, that which has most tension, that is, the direct one, passes in excess, and the more so the greater the distance of P and P′ up to a certain limit at which neither pass. There are then at P and P′ nothing but tensions alternately in contrary directions.

The effects of the coil, like those of the battery, may be classed under the heads *physiological*, *chemical*, *calorific*, *luminous*, *mechanical;* with this difference, that they are enormously more intense.

The *physiological* effects of Ruhmkorff's coil are very powerful; in fact, the shocks are so violent that many experimenters have been suddenly prostrated by them. A rabbit may be killed with two of Bunsen's elements, and a somewhat larger number of couples would kill a man.

The *calorific* effects are also easily observed; it is simply necessary to interpose a very fine iron wire between the two ends P and P′ of the induced wire; this iron wire is immediately melted, and burns with a bright light. A curious phenomenon may here be observed, namely, that when each of the wires P and P′ terminates in a very fine iron wire, and these two are brought near each other, the wire corresponding to the negative pole alone melts, indicating that the tension is greater at the negative than at the positive pole.

The *chemical* effects are very varied, inasmuch as the apparatus produces both dynamical electricity and electricity in a high state of tension. Thus, according to the shape and distance of the platinum electrodes immersed in water, and to the degree of acidulation of the water, either luminous effects may be produced in water without decomposition, or the water may be decomposed and the mixed gases disengaged at the two poles, or the decomposition may take place, and the mixed gases separate either at a single pole or at both poles.

Gases may also be decomposed or combined by the continued action of the spark from the coil. Becquerel and Frémy have found that if the current of a Ruhmkorff's coil be passed through a hermetically sealed tube containing air, as shown in fig. 705, nitrogen and oxygen combine to form nitrous acid.

The *luminous* effects of Ruhmkorff's coil are also very remarkable, and vary according as they take place in air, in vapour, or in very rarefied vapours. In air the coil produces a very bright loud spark, which, with the largest-sized coils, has a length of 18 inches. In vacuo the effects are also remarkable. The experiment is made by connecting the two wires of the coil P and P′ with the two rods of the electrical egg (fig. 576) used for producing in vacuo the luminous effects of the electrical machine. A vacuum having been produced up to 1 or 2 millimeters, a beautiful luminous trail is produced from one knob to the other, which is virtually constant, and has the same intensity as that obtained with a powerful electrical machine when the plate is rapidly turned. This experiment is shown in fig. 711. Figure 709 represents a remarkable deviation which light undergoes when the hand is presented to the egg.

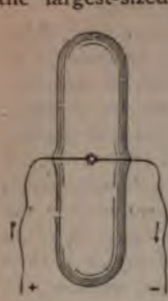


Fig. 705.

The positive pole of the current shows the greatest brilliancy; its light is of a fiery red, while that of the negative pole is of a feeble violet colour; moreover, the latter extends along all the length of the negative rod, which is not the case with the positive pole.

The coil also produces mechanical effects so powerful that with the largest apparatus glass plates two inches thick have been perforated. This result, however, is not obtained by a single charge, but by several successive charges.

The experiment is arranged as shown in fig. 706. The two poles of the induced current correspond to the binding screws *a* and *b*; by means of a copper wire, the pole *a* is connected with the lower part of an apparatus for piercing glass like that already described (fig. 581), the other pole is attached to the other conductor by a wire *d*. The latter is insulated in a large glass tube *r*, filled with shellac, which is run in while in a state of fusion. Between the two conductors is the glass to be perforated, V. When this presents too great a resistance, there is danger

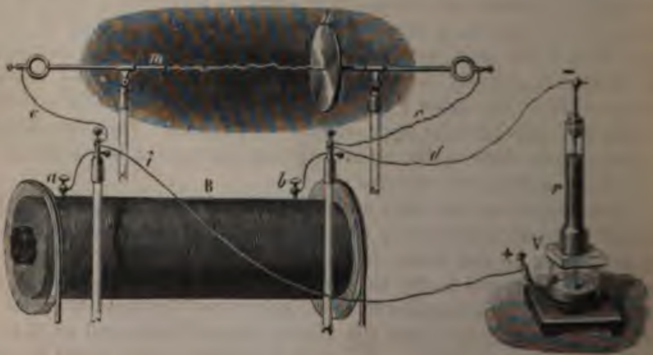


Fig. 706.

lest the spark pass in the coil itself, perforating the insulating layer which separates the wire, and then the coil is destroyed. To avoid this, two wires, *e* and *c*, connect the poles of the coil with two metallic rods whose distance from each other can be regulated. If then the spark cannot penetrate through the glass, it bursts across, and the coil is not injured.

The coil can also be used to charge Leyden jars. With a large coil giving sparks of 6 to 8 inches, and using 6 Bunsen's elements with a large surface, Ruhmkorff charged large batteries of 6 jars each, having about 3 square yards of coated surface.

The experiment with a single Leyden jar (fig. 707) is made as follows.

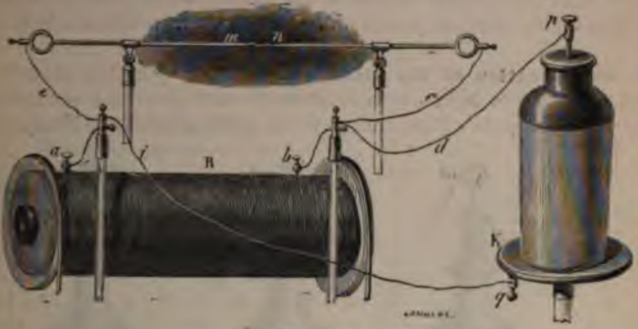


Fig. 707.

The armatures of the latter are in connection with the poles of the coil by the wires *d* and *i*, and these same poles are also connected, by means of

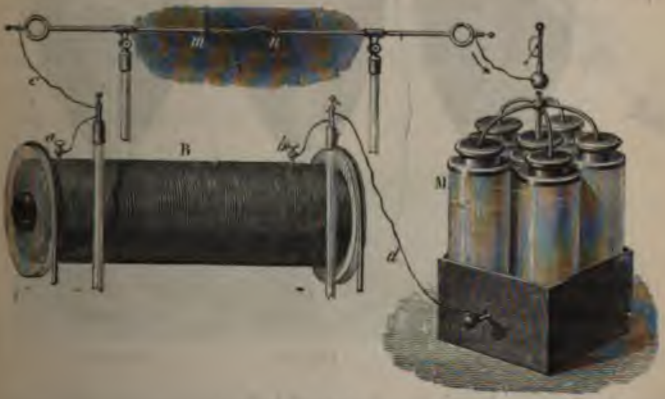


Fig 708.

the wires *e* and *c*, with the two horizontal rods of a universal discharger (fig. 570). The jar is then being constantly charged by the wires *i* and *d*, sometimes in one direction and sometimes in another, and as constantly discharged by the wires *e* and *c*; the discharge from *m* to *n* taking place as a spark two or three inches in length, very luminous, and producing a deafening sound; they are not the sparks of the electrical machine, but rather true lightning discharges.

To charge a battery the form of the experiment is somewhat varied; the external coating being connected with one pole of the coil by the wire *d*, and the internal coating with the other by the rods *m*, *n*, and the wire *c*. The rods *m* and *n* are not, however, in contact. If they were, as the two currents, the inverse and direct, pass equally, the battery would not be constantly charged and discharged; while from the distance between *m* and *n* the direct current, that of opening, which has higher tension, passes alone, and it is this which charges the battery.

842. **Stratification of the electric light.**—M. Quet has observed, in studying the electric light which Ruhmkorff's coil gives in a vacuum, that if some of the vapour of turpentine, wood spirit, alcohol, or bisulphate of carbon, etc., be introduced into the vessel before exhaustion, the aspect of the light is totally modified. It appears then like a series of alternately bright and dark zones, forming a pile of electric light between the two poles (fig. 710).

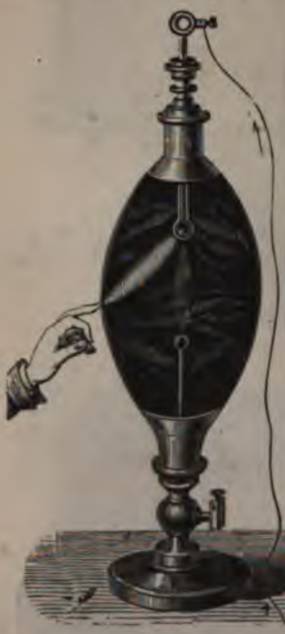


Fig. 709.

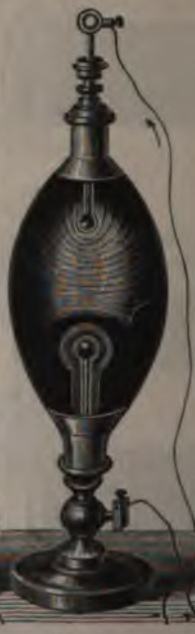


Fig. 710.

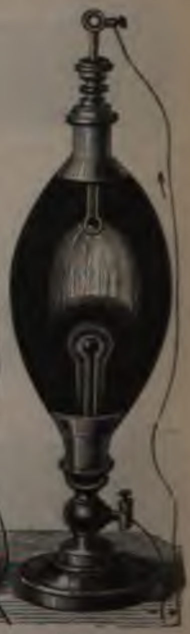


Fig. 711.

In this experiment it follows from the discontinuity of the current of induction, that the light is not continuous, but consists of a series of discharges which are nearer each other in proportion as the hammer *a* (fig. 703) oscillates more rapidly. The zones appear to possess a rapid gyratory and undulatory motion. M. Quet considers this as an optical illusion; for if the hammer is slowly moved by the hand, the zones appear very distinct and fixed.

The light of the positive pole is most frequently red, and that of the negative pole violet. The tint varies, however, with the vapour or gas in the globe.

M. Despretz has observed that the phenomena obtained by Ruhmkorff and by Quet, with a discontinuous current, are also reproduced with an ordinary continuous current, with this important difference, that the continuous current requires a considerable number of couples, while the discontinuous current of the coil only requires a single element. It is remarkable that the luminous effects of this coil are very little increased by an increase in the number of elements.

843. **Geissler's tubes.**—The brilliancy and beauty of the stratification of the electric light are most remarkable when the discharge of the Ruhmkorff's coil takes place in glass tubes containing a highly rarefied vapour or gas. These phenomena, which have been investigated by Masson, Grove, Gassiot, Plücker, etc., are produced by means of sealed glass tubes constructed by Geissler, of Bonn. These tubes are filled with different gases or vapours, and are then exhausted, so that the pressure does not exceed half a millimeter. At the ends of the tubes two platinum wires are soldered into the glass.

When the two platinum wires are connected with the ends of a Ruhmkorff's coil, magnificent lustrous striæ, separated by dark bands, are produced all through the tube. These striæ vary in shape, colour, and lustre with the degree of the vacuum, the nature of the gas or vapour, and the dimensions of the tube. The phenomenon has occasionally a still more brilliant aspect from the fluorescence which the electric discharge excites in the glass.

Fig. 712 represents the striæ given by hydrogen under half a millimeter of pressure; in the bulbs the light is white, in the capillary parts it is red.

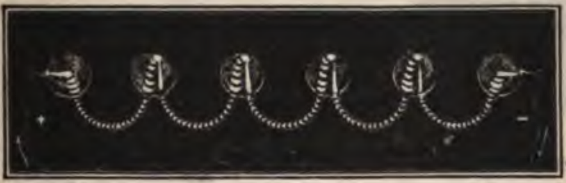


Fig .712.

Fig. 713 shows the striæ in carbonic acid under a quarter of a millimeter pressure ; the colour is greenish, and the striæ have not the same form as hydrogen. In nitrogen the light is orange yellow.

Plücker has found that the light in Geissler's tubes does not depend on the substance of the electrodes, but simply on the nature of the gas or vapour in the tube. He has found that the lights furnished by hydrogen, nitrogen, carbonic oxide, etc., give different spectra when they are decomposed by a prism. The discharge of the coil which passes through a highly rarefied gas would not pass through a perfect vacuum, and the presence of a ponderable substance is absolutely necessary for the passage of electricity.

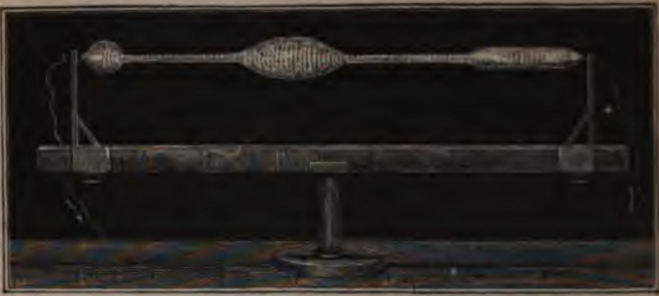


Fig. 713.

By the aid of a powerful magnet Plücker tried the action of magnetism on the electric discharge in a Geissler's tube, as Davy had done with the ordinary voltaic arc, and obtained many curious results, one of which may be mentioned. He found that where the discharge is perpendicular to the line of the poles, it is separated into two distinct parts, which can be referred to the different action exerted by the electromagnet on the two extra currents produced in the discharge.

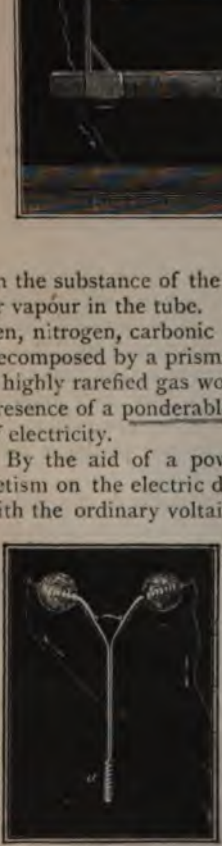


Fig. 714.

The light of Geissler's tubes has been recently applied to medical purposes. A long capillary tube is soldered to two bulbs provided with platinum wires ; this tube is bent in the middle, so that the two branches touch, and their extremities are twisted, as shown at *a* in fig. 696. This tube contains a highly rarefied gas, like those previously described, and, when the discharge passes, a light is produced at *a*, bright enough to illuminate any cavity of the body into which the tube is introduced.

844. **Rotation of induced currents by magnets.**—De la Rive has recently devised an experiment which shows in a most ingenious manner that magnets act on the light in Geissler's tubes in accordance with the laws with which they act on any other moveable conductor.

This apparatus consists of a glass globe or electrical egg (fig. 715), provided at one end with two stopcocks, one of which can be screwed on the air pump, and the other, which is a stopcock like that of Gay Lussac (354), serves to introduce a few drops of liquid into the globe. At the other end a tubulure is cemented, through which passes a rod of soft iron about $\frac{4}{5}$ of an inch in diameter, the top of which is about the centre of the globe. Except at the two ends, this bar is entirely covered with a very thick insulating layer of shellac, then with a glass tube also coated with shellac, and finally with another glass tube uniformly coated with a layer of wax. This insulating layer must be at least $\frac{2}{5}$ of an inch thick. Inside the globe the insulating layer is surrounded at *x* with a copper ring connected by means of a copper wire with a binding screw, *c*.

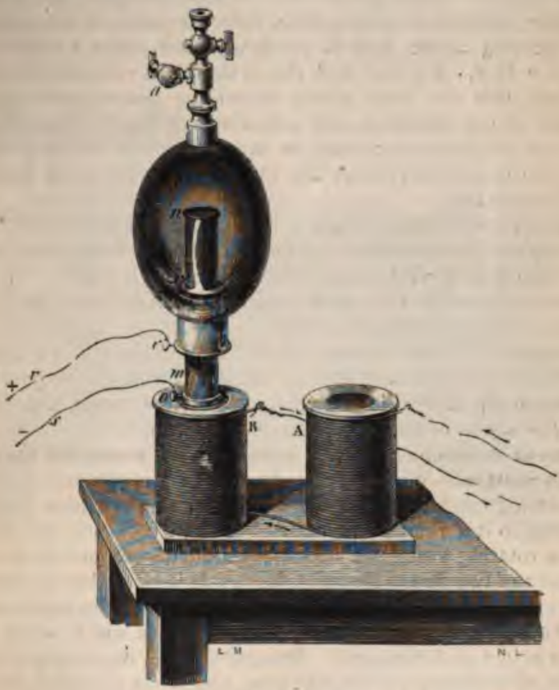


Fig. 715.

The vessel having been exhausted as completely as possible, a few drops of ether or of turpentine are introduced by means of the stopcock *a*; it is again exhausted, so that the vapour remaining is highly rarefied.

A thick disc of soft iron, *o*, provided with a binding screw, is then placed on one of the branches of a powerful electromagnet, and the end m of the rod mn is placed on this disc, while at the same time one of the ends of the secondary wire of Ruhmkorff's coil is connected with the binding screw c, and the other with the knob o. If then the coil is worked without setting in action the electromagnet, the electricity of the wire s passes to the top n of the soft iron rod, and that of the second wire to the ring x, and a more or less irregular luminous sheaf appears on the inside of the globe round the rod as in the experiment of the electric egg.

But if a voltaic current passes into the electromagnet, the phenomenon is different; instead of starting from different points of the upper surface n, and the ring x, the light is condensed and emits a single luminous arc from n to x. Further, and this is the most remarkable part of the experiment, this arc turns slowly round the magnetised cylinder mn, sometimes in one direction, and sometimes in another, according to the direction of the induced current, or the direction of the magnetism. As soon as the magnetism ceases the luminous phenomenon reverts to its original appearance.

This experiment is remarkable as having been devised *à priori* by De la Rive to explain, by the influence of terrestrial magnetism, a kind of rotatory motion from east to west, observed in the aurora borealis. The rotation of the luminous arc in the above experiment can evidently be referred to the rotation of currents by magnets.

Geissler has constructed a very useful form of the above experiment, in which the globe is exhausted once for all. Apart from the purpose for which it was originally devised it is a very convenient arrangement for demonstrating the action of magnets on movable currents.

845. **Heat developed by the induction of powerful magnets on bodies in motion.**—We have already seen in Arago's experiments (802) that a rotating copper disc acts at a distance on a magnetic needle, communicating to it a rotatory motion. We shall presently see that a cube of copper, rotating with great velocity, is suddenly stopped by the influence of the poles of two strong magnets (847). It is clear that in order to prevent the rotation of the needle or of the copper, a certain mechanical force must be consumed in overcoming the resistance which arises from the inductive action of the magnet. Reasoning upon the theory of the transformation of mechanical work into heat, which has occupied physicists in the last few years (461), it has been attempted to ascertain what quantity of heat is developed by the action of induced currents under the influence of powerful magnets. Joule, with a view of determining the mechanical equivalent of heat, coiled a quantity of copper wire round a cylinder of soft iron, and having enclosed the whole in a glass tube full of water, he imparted to the system a rapid rotation between the branches of an electromagnet. A thermometer placed in the liquid served to measure the quantity of heat produced by the induced currents in the soft iron and the wire round it. It was thus found that the heat developed was proportional to the square of the magnetism evoked, and was equivalent to the work used in the rotation.

Foucault has recently made a remarkable experiment by means of the pparatus represented in fig. 716. It consists of a powerful electromagnet xed horizontally on a table. Two pieces of soft iron, A and B, are in ontact with the poles of the magnet, and becoming magnetic by induc-on, they concentrate their magnetic inductive action on the two faces of metallic disc, D; this disc, which is of copper, is 3 inches in diameter, nd a quarter of an inch thick, partly projects between the pieces A and , and can be moved by means of a handle and a series of toothed heels with a velocity of 150 to 200 turns in a second.

So long as the current does not pass through the wire of the electro-agnet, very little resistance is experienced in turning the handle, and hen once it has begun to rotate rapidly, and is left to itself, the rotation ontinues in virtue of the acquired velocity. But if the current passes, e disc and other pieces stop almost instantaneously; and if the handle turned considerable resistance is felt. If, spite of this, the rotation be ontinued, the force used is transformed into heat, and the disc becomes eated to a remarkable extent. In an experiment made by M. Foucault e temperature of the disc rose from 10° to 61°, the current being formed three of Bunsen's elements; with six the resistance was such that the tation could not long be continued.

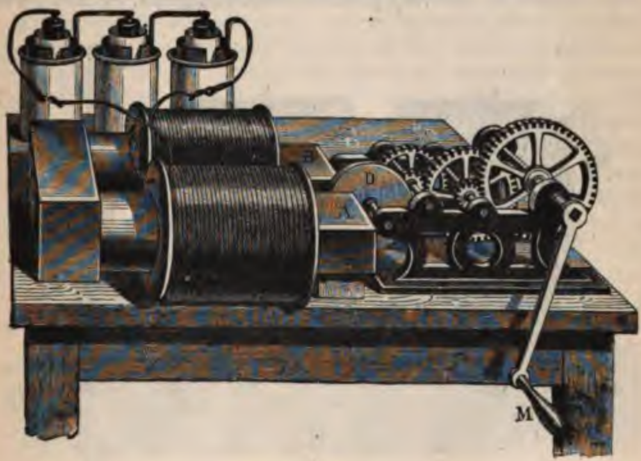


Fig. 716.

CHAPTER VII

OPTICAL EFFECTS OF POWERFUL MAGNETS. DIAMAGNETISM.

846. **Optical effects of powerful magnets.**—Faraday observed in 1845, that a powerful electromagnet exercises an action on many substances, such that if a polarised ray traverses them in the direction of the line of the magnetic poles, the plain of polarisation is deviated either to the right or to the left, according to the direction of the magnetism.

Figure 717 represents Faraday's apparatus, as constructed by Ruhmkorff. It consists of two very powerful electromagnets, M and N, fixed on two iron supports, OO′, which can be moved on a support, K. The current from a battery of 10 or 11 Bunsen's elements passes by the wire A to the commutator H, the bobbin M, and then to the bobbin N, by the wire *g*, descends in the wire *i*, passes again to the commutator, and emerges at B. The two cylinders of soft iron, which are in the axis of the bobbins, are perforated by cylindrical holes, to allow the luminous rays to pass. At *b* and *a* there are two Nicol's prisms, the first serving as polariser, and the second as analyser. By means of a limb this latter is turned round the centre of a graduated circle, P.

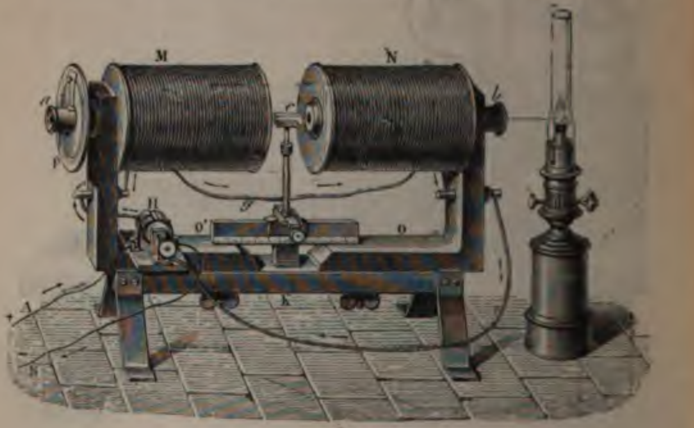


Fig. 717.

The two prisms being then placed so that their principal sections are perpendicular to each other, the prism *a* completely extinguishes the light transmitted through the prism *b*. If at *c*, on the axis of the two coils, a plate be placed with parallel faces, either of ordinary or flint glass, light is still extinguished so long as the current does not pass; but when the communications are established, the light reappears. It is now coloured, and if the analyser be turned from left or right, according to the direction of the current, the light passes through the different tints of the spectrum, as is the case with plates of quartz cut perpendicularly to the axis (622). Becquerel has shown that a large number of substances can also rotate the plane of polarisation under the influence of powerful magnets. Faraday assumes that in these experiments the rotation of the plane of polarisation is due to an action of the magnets on the luminous rays, while Biot and Becquerel ascribe the phenomena to a molecular action of the magnet on the transparent bodies submitted to its influence.

847. **Diamagnetism.**—Coulomb observed, in 1802, that magnets act upon all bodies in a more or less marked degree; this action was at first attributed to the presence of ferruginous particles. Brugmann also found that certain bodies, for instance, bars of bismuth, when suspended between the poles of a powerful magnet, do not set *axially* between the poles, that is, in the line joining the poles, but *equatorially*, or at right angles to that line. This phenomenon was explained by the assumption that the bodies were transversely magnetic. Faraday made the important discovery in 1845 that all solids and liquids are either attracted or repelled by a powerful electromagnet. The bodies which are attracted are called magnetic or *paramagnetic* substances, and those which are repelled are *diamagnetic* bodies. Among the metals, iron, nickel, cobalt manganese, platinum, cerium, osmium, and palladium are magnetic; while bismuth, antimony, zinc, tin, mercury, lead, silver, copper, gold and arsenic are diamagnetic, bismuth being the most so and arsenic the least. The diamagnetic effects can only be produced by means of very powerful magnets, and it is by means of Faraday's apparatus that they have been discovered and studied. In experimenting on the diamagnetic effects—solids, liquids, and gases—armatures of soft iron, S and Q, (figs. 700–702) of different shapes are screwed on the magnets.

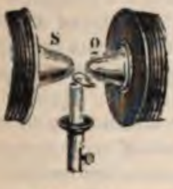


Fig. 718.

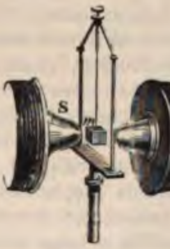


Fig. 719.

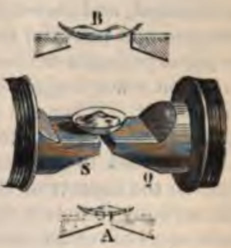


Fig. 720.

i. *Diamagnetism of solids.* If a small cube of copper suspended by a fine silk thread between the poles of the magnet (fig. 701), be in rapid rotation between the poles of an electromagnet, it stops the moment the current passes through the bobbins. If the moveable piece have the form of a small rectangular bar it sets *equatorially*, or at right angles to the axis of the bobbins, if it is a diamagnetic substance, such as bismuth antimony, or copper; but *axially*, or in the direction of the axis, if it is a magnetic substance, such as iron, nickel, or cobalt.

Besides the substances enumerated above, the following are diamagnetic: rock crystal, alum, glass, phosphorus, sulphur, sugar, bread; and the following are magnetic: many kinds of paper and sealing-wax, fluorspar, graphite, charcoal, etc.

ii. *Diamagnetism of liquids*. Liquids also present the phenomena of magnetism and of diamagnetism. In making the experiment, very thin glass tubes filled with the substance are suspended between the poles instead of the cube *m* in t If the liquids are magnetic, such as solutions of iron or coba et axially; if diamagnetic, like water, alcohol, ether, essence ne, and most saline solutions, the tubes set equatorially.

Very remarkable changes ta the direction of magnetic and diamagnetic substances when spended in liquids. A magnetic substance is indifferent in an trong magnetic liquid; it sets equatorially in a stronger m ance, and axially in a substance which is less strongly magne ially in all diamagnetic liquids.

A diamagnetic substance surrounded by a magnetic or diamagnetic substance sets equatorially. According to its composition, glass is sometimes magnetic and sometimes diamagnetic, and as in these investigations glass tubes are used for containing the liquids, its deportment must first be determined, and then taken into account in the experiment.

The action of powerful magnets on liquids may also be observed in the following experiment devised by Plücker. A solution of a magnetic liquid is placed on a watch glass between the two poles, S and Q, of a powerful electromagnet. When the current passes, the solution forms the enlargement represented in fig. 720; this continues as long as the current passes, and is produced to different extents with all magnetic liquids. The changes in the aspects of the liquids are, however, so small as to require careful scrutiny to detect their existence. A method of magnifying these changes so as to render them visible to large audiences, has recently been devised by Mr. Barrett. A source of light is placed above the watch glass containing a drop of the solution to be tried. Below the watch glass, and between the legs of the magnet, is placed a mirror at the angle of 45°. By this means the beam of light passing through the watch glass is reflected at right angles on to a screen, where an image of the drop is focussed by a lens. If now a drop of a diamagnetic liquid, such as water, or better sulphuric acid, be placed on the watch glass, as soon as the current passes, the flattened drop retreats from the two poles, and gathers itself up into a little heap, as at A (fig. 720). So doing it forms a double convex lens, by which the light is brought to a short focus below the drop, an effect instantly seen on the screen. When the current is interrupted the drop falls, and the light returns to its former appearance. A magnetic liquid, such as a solution of perchloride of iron, has exactly the opposite effect. The drop attracted to the two poles becomes flattened, and instead of a plano-convex shape, at which it rests, it becomes nearly concavo-convex, as at B. The light is dispersed, and the effect manifest on the screen. Instead of a mirror and lens, a sheet of white paper may be placed in an inclined position under the watch glass, and the effects are somewhat varied, but equally well pronounced.

iii. *Diamagnetism of gases.* Bancalari observed that the flame of a candle placed between the two poles in Faraday's apparatus was strongly repelled (fig. 718). All flames present the same phenomenon to different extents, resinous flames or smoke being most powerfully affected.

The magnetic deportment of gases may be exhibited for lecture purposes by inflating soap bubbles with them between the poles of the electromagnet, and projecting on them either the lime or the electric light.

Faraday has experimented on the magnetic or diamagnetic nature of gases. He allowed gas mixed with a small quantity of a visible gas or vapour, so as to render it perceptible, to ascend between the two poles of a magnet, and observed their deflections from the vertical line in the axial or equatorial direction ; in this way he found that oxygen was least, nitrogen more, and hydrogen most diamagnetic. With iodine vapour, produced by placing a little iodine on a hot plate between the two poles, the repulsion is strongly marked. Becquerel, who has made important researches on magnetism, has found that oxygen is most strongly magnetic of all gases, and that a cubic yard of this gas condensed would act on a magnetic needle like 5·5 grains of iron. Faraday has found that oxygen, although magnetic under ordinary circumstances, becomes diamagnetic when the temperature is much raised, and that the magnetism or diamagnetism of a substance depends on the medium in which it is placed. A substance, for instance, which is magnetic in vacuo, may become diamagnetic in air.

In the crystallised bodies which do not belong to the regular system, the directions in which the magnetism or diamagnetism of a body is most easily excited, are generally related to the crystallographic axis of the substance. The optic axis of the uniaxial crystals sets either axially or equatorially when a crystal is suspended between the poles of an electromagnet. Faraday has assumed from this the existence of a magnetocrystalline force, but it appears probable from Knoblauch's researches, that the action arises from an unequal density in different directions, inasmuch as unequal pressure in different directions produces the same result.

According to Plücker, for a given unit of magnetising force, the specific magnetisms developed in equal weights of the undermentioned substances are represented by the following numbers, those bodies with the minus sign prefixed being diamagnetic:—

Iron	1,000,000	Nickel oxide	287
Cobalt	1,009,000	Water	−25
Nickel	465,800	Bismuth	−23·6
Iron oxide	759	Phosphorus	−13·1

iv. *Detonation produced by the rupture of a current under the influence of a powerful electromagnet.* The following experiment devised by Ruhmkorff is a remarkable effect of Faraday's apparatus. When the two ends of a stout wire in which the current of the electromagnet passes are placed between the two poles, S and Q, of figure 718, that is to say, when the current is closed between S and Q, this closing takes place without a spark and without noise, or merely a feeble noise and a spark. But when the two ends are separated, and the current is hence broken, a violent noise is heard almost as strong as the report of a pistol. It would appear to be the extra current, the i hich is greatly increased by the influence of the two poles.

CH VIII.

THERMO- CURRENTS.

848. **Thermo-electricity.**—I ofessor Seebeck, in Berlin, found that by heating one of the junctio etallic circuit, consisting of two metals soldered together, an electric current was produced. This phenomenon may be shown by means of the apparatus represented in fig. 721, which consists of a plate of copper, *mn*, the ends of which are bent

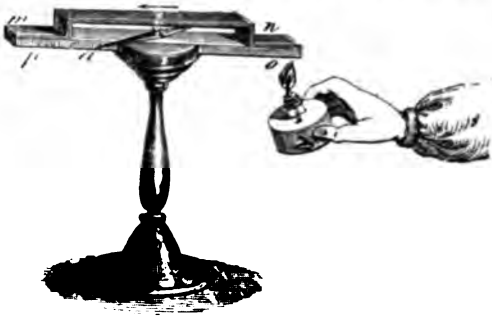


Fig. 721.

and soldered to a plate of bismuth, *op*. In the interior of the circuit is a magnetic needle moving on a pivot. When the apparatus is placed in the magnetic meridian, and one of the solderings gently heated, as shown in the figure, the needle is deflected in a manner which indicates the passage of a current from *n* to *m*, that is, from the heated to the cool junction in the copper. If, instead of heating the junction *n*, it is cooled by ice or by placing upon it cotton wool moistened with ether, the other junction remaining at the ordinary temperature, a current is produced, but in the opposite direction ; that is to say, from *m* to *n*. In both cases the current is more energetic in proportion as the *difference* in temperature of the solderings is greater.

Seebeck gives the name *thermo-electric* to this current, and the couple vhich produces it, to distinguish it from the *hydro-electric* or ordinary 'oltaic current and couple.

849. **Thermo-electric series.**—If small bars of two different metals re soldered together at one end while the free ends are connected with he wires of a galvanometer, and if now the point of junction of the two netals be heated, a current is produced, the direction of which is indi-ated by the deflection of the needle of the galvanometer. Moreover, he intensity of the current calculated from the deflection of the galva-ometer is proportional to the electromotive force of the *thermo-element.* 3y experimenting in this way with different metals, they may be formed n a list such that each metal gives rise to positive electricity when asso-iated with one of the following, and negative electricity with one of those hat precede;—that is, that in heating the soldering, the positive current oes from the positive to the negative metal across the soldering, just as the soldering represented the liquid in a hydro-electrical element; hence ut of the element, in the connecting wire in the galvanometer for instance, e current goes from the negative to the positive metal.

Thus a couple, bismuth-antimony, heated at the junction would corre-pond to a couple, zinc-copper, immersed in sulphuric acid. The following a list drawn up from Dr. Matthiessen's researches, which also gives omparative numerical values for the electromotive force.

Bismuth	+25	Gas coke	–0·1	
Cobalt	9	Zinc	0·2	
Potassium	5·5	Cadmium	0·3	
Nickel	5	Strontium	2·0	
Sodium	3	Arsenic	3·8	
Lead	1·03	Iron	5·2	
Tin	1	Red phosphorus	9·6	
Copper	1	Antimony	9·8	
Platinum	0·7	Tellurium	179·9	– ?
Silver	1·0	Selenium	–290·0	

The meaning of the numbers in this list is that, taking the electromo-ive force of the copper-silver couple as unity, the electromotive force of ny pair of metals is expressed by the difference of the numbers where he signs are the same and by the sum where the signs are different. 'hus the electromotive force of a bismuth-nickel couple would be 25 – 5 = 20; of a cobalt-iron 9 – (– 5·2) = 14·2, and of an iron-antimony – 5·2 - 9·8 = – 4·6. Where the positive sign is fixed, the current is from the ther metal to silver across the soldering; and where the negative from ilver to that metal.

Hence of these bodies, bismuth and selenium produce the greatest lectromotive force; but from the expense of this latter element, and on ccount of its low conducting power, antimony is generally substituted. 'he antimony is the negative metal but the positive pole, and the bis-uth the positive metal but the negative pole, and the current goes from ismuth to antimony across the junction.

If copper wires connected with the ends of a galvanometer are soldered together to the ends of an antimony rod, and if one of the junctions is heated to 50°, the other being maintained at 0°, a certain deflection is observed in the galvanometer. If similarly a compound bar, consisting of antimony and tin soldered together, be connected with the ends of the galvanometer, and if the junction copper-tin, and the junction tin-antimony, be heated to 50°, while the junction antimony-copper is kept at 0°, the deflection is the same as in the previous case. Hence the electromotive force produced by heating the two junctions, copper-tin and tin-antimony, is equal to the electromotive force produced by heating the copper-antimony.

Becquerel found with a number of couples where one end of the junction was heated to a given temperature and the other kept at 0°, that the intensity of the current was proportional to the temperature at the junction. If the two junctions are at any given temperature, the intensity of the current is proportional to the difference of the temperature of the two places, provided that this does not exceed 50°.

The direction of the current frequently changes when the temperature of the couple is raised beyond a certain limit. Thus, in a copper and iron circuit, the current goes from copper to iron through the heated part, provided the temperature does not exceed 300°; at a higher temperature the current changes its direction, and goes from iron to copper.

As compared with ordinary hydro-electric currents the electromotive force of thermocurrents is very small; thus the electromotive force of a bismuth-copper element with a difference of 100° C. in the temperatures of their junctions is according to Wheatstone $\frac{1}{95}$, and according to Neumann $\frac{1}{256}$ that of Daniell's element: the electromotive force of an iron-argentan couple with 10 to 15° difference of temperatures in their junctions is $\frac{1}{6600}$ that of a Daniell's, according to Kohlrausch.

850. **Causes of thermo-electric currents.**—The thermo-electric currents cannot be attributed to contact, for they can be produced in circuits formed of a single metal. Nor do they arise from chemical actions, for Becquerel has found that they are formed in hydrogen, and even in vacuo. The same physicist ascribes them to the unequal propagation of heat in the different parts of the circuit. He found that when all the parts of a circuit are homogeneous, no current is produced on heating, because the heat is equally propagated in all directions. This is the case if the wires of the galvanometer are connected by a second copper wire. But if the uniformity of this is destroyed by coiling it in a spiral, or by knotting it, the needle indicates by its deflection a current going from the heated part to that in which the homogeneity has been destroyed. If the ends of the galvanometer wires be coiled in spiral, and one end is heated and touched with the other, the current goes from the heated to the cooled end.

When two plates of the same metal, but at different temperatures, are placed in a fused salt such as borax, which conducts electricity but exerts no chemical action, a current passes from the hotter metal through the used salt to the colder one. Hot and cold water in contact produce a urrent which goes from the warm water to the cold.

Svanberg has found that the thermo-electromotive force is influenced y the crystallisation; for instance, if the cleavage of bismuth is parallel o the face of contact, it is greater than if both are at right angles, and hat the reverse is the case with antimony. Thermo-electric elements may e constructed of either two pieces of bismuth or two pieces of antimony, f in the one the principal cleavage is parallel to the place of contact, nd in the other is at right angles. Hence the position of metals in the hermo-electric series is influenced by their crystalline structure.

851. **Thermo-electric couples.**—From what has been said it will be nderstood that a thermo-electric couple onsists of two metals soldered together, he two ends of which can be joined by conductor. Fig. 722 represents a bisnuth-copper couple; fig. 723 represents series of couples used by M. Pouillet. t consists of a bar of bismuth bent twice t right angles, at the ends of which are oldered two copper strips, *c*, *d*, which erminate in two binding screws fixed on ome insulating material.

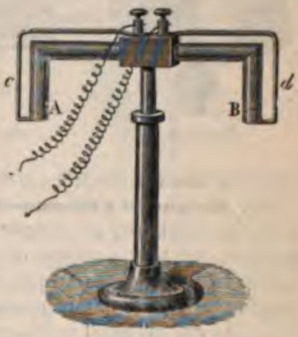


Fig. 722.

When several of these couples are oined so that the second copper of the rst is soldered to the bismuth of the econd, then the second copper of this o the bismuth of the third, and so on, this arrangement constitutes a hermo-electric battery, which is worked by keeping the odd solderings, or instance, in ice, and the even ones in water, which is kept at 100°.

852. **Nobili's thermo-electric pile.**—Nobili devised a form of thermolectric battery, or pile as it is usually termed, in which there are a large umber of elements in a very small space. For this purpose he joined e couples of bismuth and antimony in such a manner, that after having

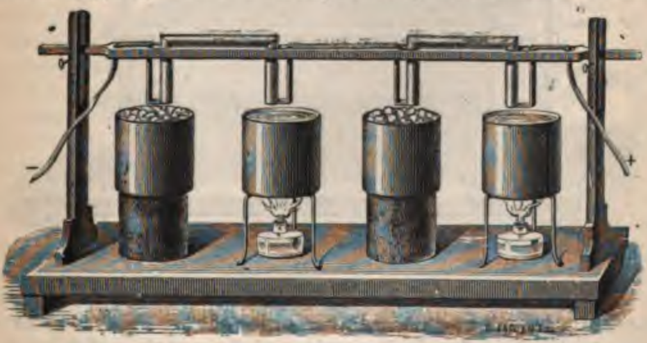


Fig. 723.

formed a series of five couples, as represented in fig. 725, the bismuth from *b* was soldered to the antimony of a second series arranged similarly; the last bismuth of this to the antimony of a third, and so on for four vertical series, containing together 20 couples, commencing by antimony, finishing by bismuth. Thus arranged, the couples are insulated from one another by means of small paper bands covered with varnish, and then enclosed in a copper frame, P (fig. 724), so that only the solderings appear at the two ends of the pile. Two small copper binding-screws, *m* and *n*, insulated in an ivory ring, communicate in the interior, one with the first antimony, representing the positive pole, and the other with the last bismuth, representing the negative pole. These binding screws communicate with the extremities of a galvanometer wire when the thermo-electric current is to be observed.

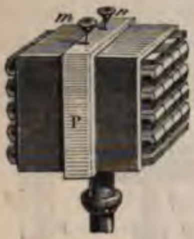


Fig. 724.

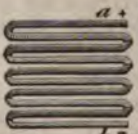


Fig. 725.

853. **Becquerel's thermo-electric battery.**—Becquerel has found that artificial sulphuret of copper heated from 200° to 300° is powerfully positive, and that a couple of this substance and copper has an electromotive force nearly ten times as great as that of the bismuth and copper couple in fig. 722. Native sulphuret, on the contrary, is powerfully negative. As the artificial sulphuret only melts at about 1035°, it may be used at very high temperatures. The metal joined with it is German silver (90 of copper and 10 of nickel). Fig. 726 represents the arrangement of a battery of 50 couples arranged in two series of 25. Fig. 728 gives on a larger scale the view of a single couple, and fig. 727 that of 6 couples in two series of 3. The sulphuret is cut in the form of rectangular prisms, 10 centimeters in length, by 18mm. in breadth, and 12mm. thick. In front is a plate of German silver *m*, intended to protect the sulphuret

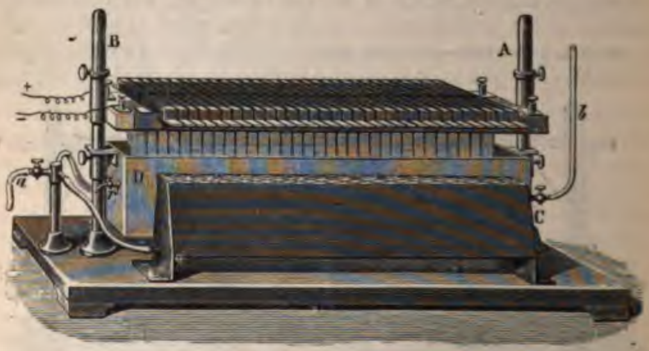


Fig. 726.

from roasting when it is placed in a gas flame. Below there is a plate of German silver MM, which is bent several times so as to be joined to the sulphuret of the next, and so on. The couples, thus arranged in two series of 25, are fixed to a wooden frame supported by two brass columns A B, on which it can be more or less raised. Below the couples there is a brass trough, through which water is constantly flowing; arriving by the tube *b* and emerging by the stopcock *r*. The plates of German silver are thus kept at a constant temperature. On each side of the trough are two long burners on the Argand principle fed by gas from a caoutchouc tube, *a*. The frame being sufficiently lowered, the ends are kept at a temperature of 200° to 300°. For collecting the current, two binding screws are placed on the left of the frame, one communicating with the first sulphuret, that is, the positive pole, and the other with the last German silver, or the negative pole. At the other end of the frame are two binding screws, which facilitate the arrangement of the couples in different ways.

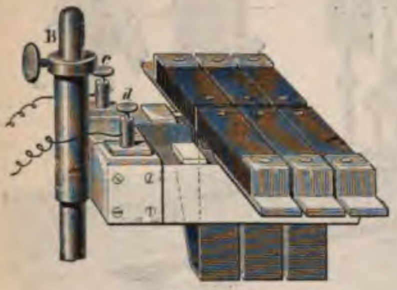


Fig. 727.

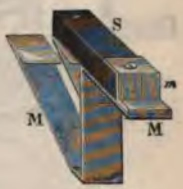


Fig. 728

The current of this battery may be used for telegraphing at a great distance, and passed into an electromagnet can lift a weight of 200 pounds. It can raise a short piece of fine iron wire to redness, and freely decomposes water. The electromotive force of a Daniell's cell is equal to about 8 or 9 of these couples.

854. **Melloni's thermomultiplier.**—We have already noticed the use which Melloni has made of Nobili's pile, in conjunction with the galvanometer, for measuring the most feeble alterations of temperature. The arrangement he used for his experiment is represented in fig. 729.

On a wooden base, provided with levelling screws, a graduated copper rule, about a yard long, is fixed edgeways. On this rule the various parts composing the apparatus are placed, and their distances can be fixed by means of binding screws. *a* is a support for a Locatelli's lamp, or other source of heat; F and E are screens; C is a support for the bodies experimented, and *m* is a thermo-electrical battery. Near the apparatus is a galvanometer, D; this has only a comparatively few turns of a tolerably thick (1 mm.) copper wire; for the electromotive force of the thermocurrents is small, and as the internal resistance is small too, for it only consists of metal, it is clear that no great resistance can be introduced into the circuit if the current is not to be completely stopped. Such galvanometers are called ***thermomultipliers***. The delicacy of this apparatus is so great that the heat of the hand is enough at a distance of a yard from the pile to deflect the needle of the galvanometer.

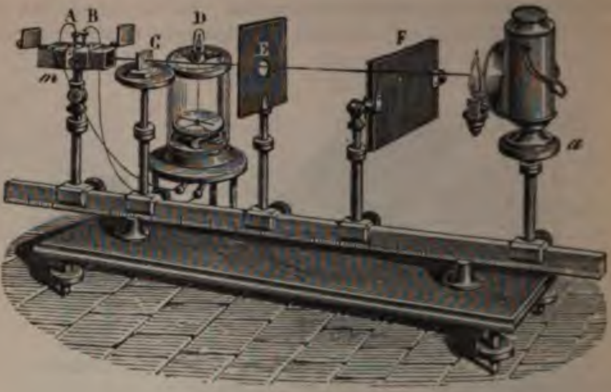


Fig. 729.

In using it for measuring temperature, the relation of the deflection of the needle, and therefore of the intensity of the current, to the difference of the temperatures of the two ends, must be determined. That known, the temperature of the ends not exposed to the source of heat being known, the observed deflection gives the temperature of the other, and therewith the intensity of the source of heat.

855. **Properties and uses of thermo-electric currents.**—Thermo-electric currents are of extremely low tension, but of great constancy; for their opposite junctions, by means of melting ice and boiling water, can easily be kept at 0° and 100° C. On this account, Ohm used them in the experimental establishment of his law. They can produce all the actions of the ordinary battery in kind, though in less degree. By means of a thermo-electrical pile consisting of 769 elements of iron and German silver, the ends of which differed in temperature by about 10° to 15°, Kohlrausch proved the presence of free positive and negative electricity at the two ends of the open pile respectively. He found that the density of the free electricity was nearly proportional to the number of elements, and also that the electromotive force of a single element under the above circumstances was about $\frac{1}{6000}$ that of a single Daniell's element. On account of their feeble tension, thermo-electric piles produce only feeble chemical actions. Botto, however, with 120 platinum and iron wires, has decomposed water.

Besides these, sparks can be obtained on breaking circuit, and magnetic and physiological effects produced as with other sources of electricity.

6. **Becquerel's electrical thermometer.**—This consists of a copper
iron wire of many yards in length soldered at their ends, but other-
insulated from each other by being covered with gutta-percha. The
er wire is cut twice and connected with the binding screws of a
ı ometer (fig. 730). One of the solderings is arranged in the place

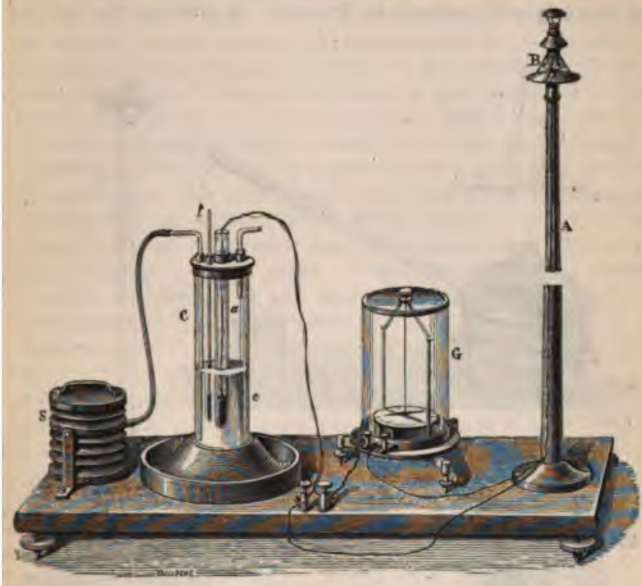


Fig. 730.

e temperature is to be measured. In the figure it is at B at the
f a mast A, and is underneath a hood, which protects it from rain
he sun, but allows air to circulate round it.

e other soldering is immersed in mercury contained in a glass tube, and
h in turn is placed in a larger cylinder C containing ether. On one
is a very delicate thermometer *t*, which indicates the temperature of
ther. By means of a small bellows S, a caoutchouc tube and a glass
a current of air can be sent through the ether, which being thus
rised is cooled. If, on the contrary, the temperature of the ether is
raised, a tinplate vessel containing hot water is brought near the
der C.

ese details being known, when the solderings are at the same
erature no current is produced in the circuit, and the galvanometer
ins at zero; but when there is the least difference in temperature, the
ction of the galvanometer tells which of these solderings is the
st. If it is the one which is immersed in the mercury, the bellows is
ed until the ether being cooled the galvanometer reverts to zero.

The two solderings being then at the same temperature, the thermometer *t* at once indicates the temperature in B.

Becquerel has applied this instrument to investigations on the temperature of the ground at various depths, that of the air at different heights, and also on the temperature of plants and animals.

857. **Becquerel's electric pyrometer.**—This apparatus is an improved form of one originally devised by Pouillet. It consists (fig. 731) of two wires, one of platinum and the other of palladium, both two meters in length and a square millimeter in section. They are not soldered at the ends, but firmly tied for a distance of a centimeter with fine platinum wire. The palladium wire is enclosed in a thin porcelain tube; the platinum wire is on the outside, and the whole is enclosed in a larger porcelain tube P. At the end of this is the junction which is adjusted in the place the temperature of which is to be investigated. At the other end project the platinum and palladium wires *m* and *n*, which are soldered to two copper wires that lead the current to a magnetometer G. These series at the junction are placed in glass tubes immersed

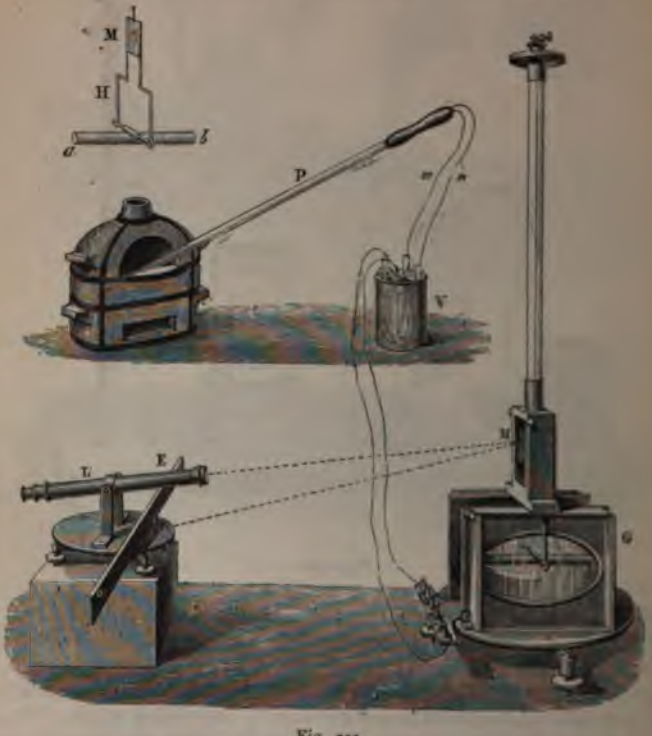


Fig. 731.

in ice, so that, being both at the same temperature, they give rise to no current.

The magnetometer which was devised by Weber is nothing more than a large galvanometer. It consists of a magnetised bar placed in the centre of a copper frame which deadens the oscillations (825) and rests on a stirrup, which in turn is suspended to a long and very fine platinum wire. On the stirrup is fixed a mirror M, which moves with the magnet, and gives by reflection the image of divisions traced on a horizontal scale E at a distance. These divisions are observed by a telescope. With this view, before the current passes, the image of the zero of the scale is brought to the micrometer wire of the telescope; then the slightest deflection of the mirror gives the image of another division, and therefore the angular deflection of the bar. This angle is always small and should not exceed 3 or 4 degrees: this is effected by placing, if necessary, a rheostate in the circuit, or any resistance coil. The angular deflection being known, the intensity of the current and the temperature of the junction are deduced from pyrometric tables. These are constructed by interpolation when the intensities are known, which correspond to two temperatures near those to be observed.

The indications of the pyrometer extend to the fusing point of the palladium.

858. **Peltier's cross.**—Peltier found that an electric current, in passing through a conductor, in some cases produces heat, in others cold. He obtained the greatest increase of temperature when the negative current passed from a good conductor of electricity to a bad one—for example, from copper to zinc; and the least increase when the positive current passed in this direction. But when a bar of bismuth and a bar of antimony were soldered together, the temperature of the air sank at the soldering when the positive current passed from the first to the second metal, and rose in the opposite case. This experiment may easily be made by hermetically fixing in two tubulures in an air thermometer, a compound bar consisting of bismuth and antimony soldered together in such a manner that the ends project on each side. The projecting parts are provided with binding screws, so as to allow a current to be passed hrough. When the positive current passes from the antimony to the bismuth, the air in the bulb is heated, it expands, and the liquid in the stem sinks; but if it passes in the opposite direction the air is cooled, it contracts, and the liquid rises in the stem. For this experiment the current must have a certain definite strength, which is found by experiment: it is best regulated by a rheostat (859).

These experiments form an interesting illustration of the principle, that whenever the effects of heat are reversed, heat is produced; and whenever he effects ordinarily produced by heat are otherwise produced, cold is the esult.

CHAPTER IX.

DETERMINATION OF ELECTRICAL CONDUCTIVITY.

859. **Rheostat.**—The rheostat is an instrument by which the resistance of any given circuit can be increased or diminished without opening the circuit. As invented by Mr. Wheatstone, it consists of two parallel cylinders, one, A, of brass, the other, B, of wood (fig. 732). In the latter there is a spiral groove, which terminates at *a* in a copper ring, to which is fixed the end of a fine brass wire. This wire, which is about 40 yards long, is partially coiled on the groove; it passes to the cylinder A, and, after a great number of turns on this cylinder, is fixed at the extremity *c*. Two binding screws, *n* and *o*, connected with the battery, communicate by two steel plates; one with the cylinder A, the other with the ring *a*.

When a current enters at *o*, it simply traverses that portion of the wire rolled on the cylinder B, where the windings are insulated by the grooves; passing thence to the cylinder A, which is of metal, and in contact with the wire, the current passes directly to *m*, and thence to *n*. Hence, if the length of the current is to be increased, the handle, *d*, must be turned from right to left. If, on the contrary, it is to be diminished, the handle is to be fixed on the axis, *c*, and turning then from left to right, the wire is coiled on the cylinder A. The length of the circuit is indicated in feet and inches, by two needles, at the end of the apparatus not seen in the figure, which are moved by the cylinders A and B.

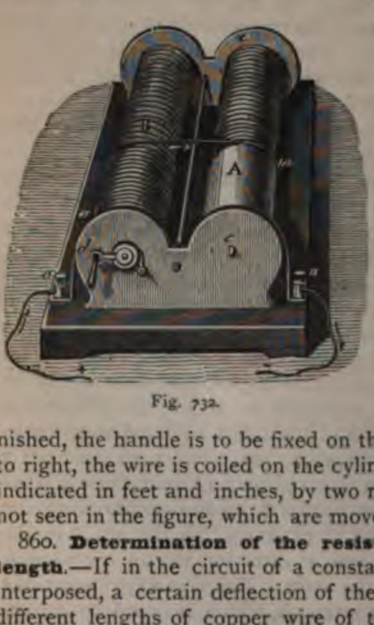


Fig. 732.

860. **Determination of the resistance of a conductor. Reduced length.**—If in the circuit of a constant element a tangent compass be interposed, a certain deflection of the needle will be produced. If, then, different lengths of copper wire of the same diameter be successively interposed, corresponding deflections will in each case be produced. Let us suppose, that in a particular case the tangent of the angle of deflection (743) observed with the element and tangent compass alone was 1·88, and that when 5, 40, 70, and 100 yards of copper wire were successively placed in the circuit, the tangents of the corresponding deflections were 0·849, 0·172, 0·105, and 0·074. Now, in this experiment, the total resistance consists of two components; the resistance offered by the element and the tangent compass, and the resistance offered by the wire in each case. The former resistance may be supposed to be equal to the resistance of

x yards of copper wire of the same diameter as that used, and then we have the following relations:

Length of wire.	*Tangent of angle of deflection.*
x yards	1·88
$x+5$ "	0·849
$x+40$ "	0·172
$x+70$ "	0·105
$x+100$ "	0·074

If the intensities of the currents are inversely as the resistances—that is, as the lengths of the circuits—the proportion must prevail,

$$x : x+5 = 0·849 : 1·886\,;$$

from which $x = 4·11$. Combining, in like manner, the other observations, we get a series of numbers, the mean of which is 4·08. That is, the resistance offered by the element and galvanometer is equal to the resistance of 4·08 yards of such copper wire, and this is said to be the *reduced length* of the element and galvanometer in terms of the copper wire.

It is of great scientific and practical importance to have a *unit* or *standard of comparison* of resistances, and numerous such have been proposed. Jacobi proposed the resistance of a meter of a special copper wire a millimeter in diameter. Copper is however ill adapted for the purpose, as it is difficult to obtain pure. Matthiessen has proposed an alloy of gold and silver, containing two parts of gold and one of silver: its conducting power is very little affected by impurities in the metals, by annealing, or by moderate changes of temperature.

Siemens' unit is a meter of pure mercury, having a section of a square millimeter. It is 0·9536 of an Ohmad or BA unit (861).

The *Varley unit*, which is used in telegraphic work, is a standard mile of a *special* copper wire $\frac{1}{16}$ of an inch in diameter. Matthiessen has proposed instead of this a mile of pure annealed copper wire $\frac{1}{16}$ in. in diameter.

861. **British Association unit of electrical resistance.**—The great importance, both theoretically and practically, of having some uniform standard for the comparison of electrical resistance has for years past engaged the attention of a committee of the British Association, which includes the principal electricians in this country. Their labours have resulted in the adoption of a standard which has received the approval of men of science both in this and other countries. The following account of this unit, which it is proposed to call the *Ohmad* or *BA unit*, has been kindly furnished by the secretary to the Committee, Mr. Fleeming Jenkin.

It represents a convenient multiple of the so-called absolute unit of electrical resistance. The word 'absolute,' as here used, does not imply accuracy of construction, but is intended to express that the measurement of electrical resistance is made by a unit which bears a definite relation to the fundamental units of time, mass, and space only; instead of being a mere comparison with the resistance of some particular piece of metal arbitrarily chosen as the unit. In a similar sense a square foot and a cubic foot may be called absolute units of surface and capacity, an acre and a gallon arbitrary units.

It seems strange at first that the unit of electrical resistance can be measured by reference to time, mass, and space only, without reference to the specific qualities of any material; but our chief knowledge of electric phenomena is derived from an observation of mechanical effects, and we need, therefore, feel no surprise at learning that those phenomena can be measured in purely mechanical units. The voltaic current, electromotive force, and resistance, quantity, and capacity can all be so measured in more than one way. The netic measurement of current is determined by the following ions. If f be the force exerted by a current of strength C, L, on a pole of a magnet; m being the magnetic strength le, and K its distance from the current, it is found by experi f varies as $\frac{CLm}{K^2}$, so that $C = \kappa \frac{fK^2}{Lm}$, where κ is some c if the unit current be that which in unit length of circuit exe on a unit pole at unit distance, we get $\kappa = 1$, and the equation for C becomes

$$C = \frac{fK^2}{Lm} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and C may be measured by the expression $\frac{fK^2}{Lm}$.

Again, for the resistance we get

$$r = \frac{W}{C^2 t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where W is the work done in the time t by a current C flowing in a circuit of the resistance r. Now, the first equation allows us to measure a current in terms of a force f, two lengths K and L, and a magnitude m, which again depends on measurements of force and length only, so that we here have a current measured in mechanical units in virtue of a mathematical relation between the phenomena produced by the current and the mechanical units. It follows from the equation that the unit current will be that of which each unit length exerts a unit force on a unit pole at unit distance. The second equation, like the first, is deduced from observation. The resistance of a circuit is found to be proportional to the work done by a current in that circuit, and inversely proportional to the square of the current and to the time during which it acts; any two circuits for which $\frac{W}{C^2 t}$ is equal have equal resistances; if this quantity for circuit A is double what it is for circuit B, then the resistance of circuit A is double that of circuit B. Therefore, we have exactly the same ground for saying that $\frac{W}{C^2 t}$ measures the resistance of the circuit that we have for saying a^2 measures the contents of a square with sides equal to a. In equation 2, W, the work, is essentially a mechanical measurement, for, though generally observed in the form of heat, it is by Joule's equivalent referred to the mechanical unit of energy or work.

Moreover from Ohm's law $C = \frac{e}{r}$ . . . . (3)

further measures electromotive force in terms of C and r, and Faraday's discovery expressed by equation

$$Q = Ct,$$

where Q is the quantity of electricity conveyed by the current C in the time t, shows how quantity is measured in the same mathematical series.

Although nothing can be simpler than the mathematical conceptions here involved, the practical measurement of resistance, or any other of the above magnitudes, by direct reference to force, work, time, etc., involves much labour, so that for each kind of measurement it is necessary for practical use to construct a standard which affords the desired measure by direct and simple comparison with the thing measured. Thus, a Frenchman to measure wine does not work out the cubic contents of a bottle, but measures the number of litres by reference to a standard litre, which is a simple decimal submultiple of the cubic metre. In like manner practical measurements of resistance are made by comparison with the Ohm or BA unit prepared to represent a simple decimal multiple (ten million times) the absolute electromagnetic unit; the metre, the gramme, and the second of time were taken as fundamental units by the committee, and one which is approximately equal to 10^7 metre seconds. Great care has been taken in the determination and construction of the standard, which is represented by several coils of wires of various metals and alloys, and by tubes of mercury which have all been adjusted to represent one and the same standard unit, the variety of materials being intended as a safeguard against possible alteration in resistance of one or more of the coils or tubes. Certified copies of the unit, consisting of coils of platinum-silver wire, are issued by the Committee through their secretary, Mr. Fleeming Jenkin. Similar standards for the measurement of currents, electromotive force, quantity, and capacity will also be issued.

The Ohmad is 1·0486 of a Siemens' unit; that is, it is equal to the resistance of a prism of pure mercury 1 square millimeter in section and 1·0486 metre in length at the temperature 0°.

862. **Equivalent conductors.**—The resistance of a conductor depends, as we have seen (759), on its length, section, and conductivity. Two conductors, C and C′, whose length, conductivity, and section are respectively λ λ', κ κ', ω ω', would offer the same resistance, and might be substituted for each other in any voltaic circuit, without altering its intensity, provided that $\frac{\lambda}{\kappa\omega} = \frac{\lambda'}{\kappa'\omega'}$; and such conductors are said to be *equivalent* to each other. An example will best illustrate the application of this principle.

It is required to know what length of a cylindrical copper wire 4 mm.

in diameter would be equivalent to 12 yards of copper wire 1 mm. in diameter.

Let $\lambda = 12$ the length of the copper wire 1 mm. in diameter, and λ' the length of the other wire; then since in this case the material is the same, the conductivity is the same, and the equation becomes $\frac{\lambda}{\omega} = \frac{\lambda'}{\omega'}$. Now the sections of the wires are directly as the squares of the diameters, and hence we have $\frac{12}{1^2} = \frac{\lambda'}{4^2}$, or $\lambda' = 12 \times 16 = 192$. That is, 192 yards of copper wire 4 mm. in thickness would only offer the same resistance as 12 yards of copper wire 1 mm. in

How thick must an ch for the same length shall offer
the same resistance as mm. in diameter?

Here the length bei he expression becomes $\kappa\omega = \kappa'\omega'$,
or since the sections are res of the diameters, $\kappa d^2 = \kappa' d'^2$.
The conductivity of cop and that of iron 0·138. Hence
we have $2·5^2 = d'^2 \times 0·138$ $0·138 = 45·3$ mm. or $d' = 6·7$ mm.
That is, any length of a 2·5 mm. in diameter might be
replaced by an iron wire ngth, provided its diameter were
6·7 mm.

863. **Determination of electrical conductivity.**—The various methods of determining the electrical conductivity of a body consist essentially in determining what length of a given section of the known body will offer the same resistance as the same length of a metallic wire of a given section taken as a standard of comparison. A description of the principle of one of these methods, known as *Wheatstone's Balance or Bridge*, will give a general idea of them.

On a base of some hard wood four stout wires are fixed, in the manner represented in figure 733. They are provided with binding screws at

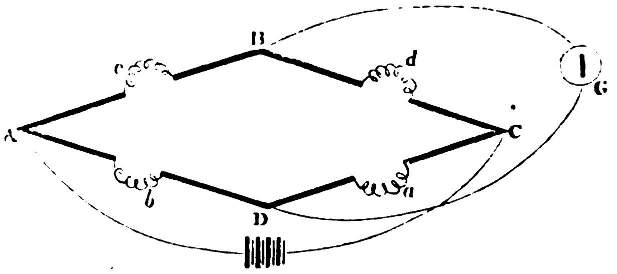


Fig. 733.

A, B, C, and D, and there are breaks at *a*, *b*, *c*, *d*, also provided with binding screws, so that any resistance may be introduced there. The points A and C are connected with the terminals of a battery, while B and D are connected with a delicate galvanometer. Now it can be shown that, if the resistances introduced at *a*, *b*, *c*, *d*, and which we will designate by these letters, bear a certain relation, no current will pass in the galvanometer.

Suppose first of all that the resistances are all equal in every respect; the current arriving at A would divide, one part would traverse the galvanometer in the direction A*c*BGD, and the other in the direction A*b*DGB; and as both these are equal and opposite in direction, no effect would be produced on the galvanometer; but if the resistances *a* and *b* are different, the tensions at B and D will be different, and accordingly a current will traverse the galvanometer either from B to D or from D to B, and the needle be deflected in a corresponding manner. If now one of the resistances can be varied—if, for instance, *c* is a rheostat—either by increasing or diminishing the amount of wire, the two resistances may be made equal, and then a current ceases to pass. We can then express one resistance, *b*, in terms of *c*.

Wheatstone's bridge, however, is more general. It can be shown that no current passes, provided that the four resistances bear to each other the ratio $a : b = d : c$. So that if *c*, for instance, is the resistance to be determined, by varying the others in a suitable manner the proportion can always be obtained. In practice two of them are generally fixed resistances of known amount, and the third is a rheostat; and, where possible, it is most convenient to take $a = b$, in which case $d = c$.

The following is a method of determining the internal resistance of an element. A circuit is formed consisting of one element, a rheostat and a galvanometer, and the intensity I is noted on the galvanometer. A second element is then joined with the first, so as to form one of double the size, and therefore half the resistance, and then by adding a length, *l*, of the rheostat wire, the intensity is brought to what it originally was. Then if E is the electromotive force, and R the resistance of an element, *r*, the resistance of the galvanometer and the other parts of the circuit; the intensity I in the one case is $I = \frac{E}{R + r}$, and in the other $= \frac{E}{\frac{1}{2}R + r + l}$, and since the intensity in both cases is the same, $R = 2l$.

864. **Electrical conductivity.**—We can regard conductors in two aspects, and consider them as endowed with a greater or less facility for allowing electricity to traverse them, a property which is termed *conductivity*; or we may consider conductors interposed in a circuit as offering an obstacle to the passage of electricity—that is, a resistance which it must overcome. A good conductor offers a feeble resistance, and a bad conductor a great resistance. Conductivity and resistance are the inverse of each other.

The conductivity of metals has been investigated by many physicists by methods analogous in general to that described in the preceding paragraph, and very different results have been obtained. This arises mainly from the different degrees of purity of the specimens investigated, but their molecular condition has also great influence. Matthiessen finds the difference in conductivity between hard-drawn and annealed silver wire to amount to 8·5, for copper 2·2, and for gold 1·9 per cent. The following are results of a series of careful experiments by Matthiessen on the electrical conductivity of metals at 0° C. compared with silver as a standard.

Silver	100·0	Iron	16·8
Copper	99·9	Tin	13·1
Gold	80·0	Lead	8·3
Aluminium	56·0	German Silver	7·7
Sodium	37·4	Antimony	4·6
Zinc	29·0	Mercury	1·6
Cadmium	23·7	Bismuth	1·2
Potassium	20·8	Graphite	0·07
Platinum	[illegible]		

The conductivity of metal[illegible]d by an increase in temperature. The law of this diminution is [illegible]y the formula

$$\kappa_t = \text{[illegible]}\ bt^2);$$

where κ_t and κ_o are the condu[illegible] and 0° respectively, and a and b are constants, which are pro[illegible]me for all pure metals. For ten metals investigated by Ma[illegible] found that the conductivity is expressed by the formula

$$K_t = K_o\,(1 - 0{\cdot}0037647t + 0{\cdot}00000834t^2).$$

Liquids are infinitely worse conductors than metals. The conductivity of a solution of one part of chloride of sodium in 100 parts of water is $\frac{1}{300000000}$ that of copper. In general acids have the highest and solutions of alkalies and neutral salts the lowest conductivity. Yet, in solutions, the conductivity does not increase in direct proportion to the quantity of salt dissolved.

The following is a list of the conductivity of a few liquids as compared with that of pure silver.

Pure silver	100,000,000·00
Nitrate of copper, saturated solution	8·99
Sulphate of copper ditto	5·42
Chloride of sodium ditto	31·52
Sulphate of zinc ditto	5·77
Sulphuric acid, 1·10 sp. gr.	99·07
" " 1·24 sp. gr.	132·75
" " 1·40 sp. gr.	90·75
Nitric acid, commercial	88·68
Distilled water	0·01

Liquids and fused conductors increase in conductivity by an increase of temperature. This increase is expressed by the formula

$$\kappa_t = \kappa_o\,(1 + at),$$

and the values of a are considerable. Thus, for a saturated solution of sulphate of copper, it is 0·0286.

By most physicists the conductivity of liquids has been regarded as a purely *electrolytic* conductivity that is due to chemical decomposition. Yet Faraday, in stating his law of electrolytic decomposition, had announced that it was subject to certain restrictions in cases in which liquids could conduct electricity without being decomposed. Foucault has recently shown by delicate experiments, that liquids have a peculiar conductivity, *a physical* conductivity analogous to that of metals. This is, however, much less than the electrolytic conductivity, but may have a distinct influence on the chemical effects of currents and on Faraday's law.

865. **Determination of electromotive force. Wheatstone's method.**—In the circuit of the element whose electromotive force is to be determined, a tangent compass and a rheostat are inserted, the latter being so arranged that the intensity I of the current is a definite amount; for example, the galvanometer indicates 45°. By increasing the amount of the rheostat wire by the length *l*, a diminished intensity, *i* (for instance, 40°), is obtained.

A second standard element is then substituted for that under trial, and by arranging the rheostat, the intensity of the current is first made equal to I, and then, by the addition of *l* lengths of the rheostat, is made $= i$.

Then if E and E_1 are the two electromotive forces, R and R_1 their resistances when they have the intensity I, and *l* and l_1 the lengths added, we have

Trial element.	Standard element.
$I = \frac{E}{R}$	$I = \frac{E_1}{R_1}$
$i = \frac{E}{R + l}$	$i = \frac{E_1}{R_1 + l_1}$

from which we have

$$E = E_1 \frac{l}{l_1}.$$

Hence the electromotive forces of the elements compared are directly as the lengths of the wire interposed.

Another method is described by Wiedemann. The two elements are connected in the same circuit with a tangent galvanometer, or other apparatus for measuring intensity, first in such a manner that their currents go in the same direction, and, secondly, that they are opposed. Then if the electromotive forces are E and E′, their resistances R and R′, the other resistances in the circuits *r*, while I_s is the intensity when the elements are in the same direction, and I_4 the intensity when they go in opposite directions, then:

$$I_s = \frac{E + E'}{R + R' + r}$$

and

$$I_4 = \frac{E - E'}{R + R' + r}$$

whence

$$E' = \frac{E\ (I_s - I_4)}{I_s + I_3}.$$

866. **Siemens' electrical resistance thermometer.**—Supposing in a Wheatstone's bridge arrangement, after the ratio $a : b = d : c$ has been es-

tablished, the temperature of one of the coils, *c*, for instance, be increased, the above ratio will no longer prevail, for the resistance of *c* will have been altered by the temperature, and if *d* be the rheostat, the length of wire must be altered so as to produce equivalence. On this idea Siemens has based a mode of observing the temperature of places which are difficult of direct access. He places a coil of known resistance in the particular locality whose temperature is to be observed; it is connected by means of long conducting wires with the place of observation, where it forms part of a Wheatstone's bridge arrangement. The resistance of the coil is known in terms of the rheostat, and by preliminary trials it has been ascertained how much additional wire m iced to balance a given increase in the temperature of the res This being known, and the apparatus adjusted at the ordinar ure, when the temperature of the resistance coil varies, this varia ıer direction is at once known by observing the quantity whic brought in or out of the rheostat to produce equivalence.

This apparatus has been of rvice in watching the temperature of large coils of telegr h, stowed away in the hold of vessels, are very liable to b It might also be used for the continuous and convenient observation of underground and submarine temperatures. If a coil of platinum wire were substituted for the copper, the apparatus could be used for watching the temperature of the interior of a furnace.

867. **Derived currents.**—In fig. 734 the current from a Bunsen's element traverses the wire *rqpnm* : let us take the case in which any two

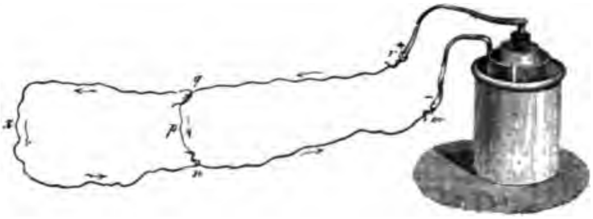


Fig. 734.

points of this circuit, *n* and *q*, are joined by a second wire, *nxq*. The current will then divide at the point *q* into two others, one of which goes in the direction *qpnm*, while another takes the direction *qxnm*. The two points *q* and *n* from which the second conductor starts and ends are called the *points of derivation*, the wire *qpn* and the wire *qxn* are *derived wires*. The currents which traverse these wires are called the *derived* or *partial currents* ; the current which travelled the circuit *rqpnm* before it branches is the *primitive current* ; and the name *principal current* is given to the whole of the new current which traverses the circuit when the derived wire has been added. The principal current is stronger than the primitive one, because the interposition of the wire *qxn* lessens the total resistance of the circuit.

If the two derived wires are of the same length and the same section, their action would be the same as if they were juxtaposed, and they might be replaced by a single wire of the same length but of twice the section, and therefore with half the resistance. Hence the current would divide into two equal parts along the two conductors.

When the two wires are of the same length but of different sections, the current would divide unequally, and the quantity which traversed each wire would be proportional to its section, just as when a river divides into two branches, the quantity of water which passes in each branch is proportional to its dimensions. Hence the resistance of the two conductors joined would be the same as that of a single wire of the same length, the section of which would be the sum of the two sections.

If the two conductors *qpn* and *qxn* are different, both in kind, length, and section, they could always be replaced by two wires of the same kind and length, with such sections that their resistances would be equal to the two conductors ; in short, they might be replaced by equivalent conductors. These two wires would produce in the circuit the same effect as a single wire, which had this common length, and whose section would be the sum of the sections thus calculated. The current divides at the junction into two parts proportional to these sections, or inversely as the resistances of the two wires.

Suppose, for instance, *qpn* is an iron wire 5 metres in length and 3 mm square in section, and *qxn* a copper wire.

The first might be replaced by a copper wire a metre in length, whose section would be $\frac{3}{5} \times \frac{1}{7}$ (taking the conductivity of copper at 7 times that of iron) or $\frac{3}{35}$ square mm. The second wire might be replaced by a copper wire a meter in length with a section of $\frac{2}{9}$ square mm. These two wires would present the same resistance as a copper wire a meter in length, and with a section of $\frac{3}{35} + \frac{2}{9} = \frac{97}{315}$ square millimeters.

The principal current would divide along the wires in two portions, which would be as $\frac{3}{35} : \frac{2}{9}$.

The most important laws of divided circuits are as follows :—

i. *The sum of the intensities in the divided parts of a circuit is equal to the intensity of the principal current.*

ii. *The intensities of the currents in the divided parts of a circuit are inversely as their resistances ; or, what is the same, the division of a current into partial currents which lie between two points is directly as the respective conductivities of these branches.*

And as problems on divided circuits frequently occur in telegraphy, the following formulæ, which include these laws, are given for a simple case.

If I be the intensity of the current in the undivided part of the circuit *rqpnm*, and if *i* is the intensity in one branch (say in the above figure *qpn*) and i' in *qxn* ; if R r and r_1 are the corresponding resistances, the electromotive force being E, then

$$I = \frac{E(r+r_1)}{Rr + Rr_1 + rr_1}$$

$$i + \frac{E r_1}{Rr + Rr_1 + rr_1}.$$

$$i = \frac{E r}{Rr + Rr_1 + rr_1}$$

The resistance R_1 of the whole circuit through which the current circulates is

$$R \qquad \frac{rr_1}{\qquad + r_1}$$

and therefore the total resistanc derived currents *qpn* and *qrn* is

CHAPTER X.

ANIMAL ELECTRICITY.

868. **Muscular currents.**—The existence of electrical currents in living muscle was first indicated by Galvani, but his researches fell into oblivion after the discovery of the Voltaic pile, which was supposed to explain all the phenomena. Since then, Nobili, Matteucci, and others, especially, in late years, Du Bois Reymond, have shown that electric currents do exist in living muscles and nerves, and have investigated their laws.

For investigating these currents it is necessary to have a delicate galvanometer, and also electrodes which will not become polarised or give a current of their own, and which will not in any way alter the muscle when placed in contact with it; the electrodes which satisfy these conditions best are those of Du Bois Reymond, as modified by Donders. Each consists of a glass tube, one end of which is narrowed and stopped by a plug of paste made by moistening china-clay with a half per cent. solution of common salt; the tube is then partially filled with a saturated solution of sulphate of zinc, and into this dips the end of a piece of thoroughly amalgamated zinc wire, the other end of which is connected by a copper wire with the galvanometer; the moistened china-clay is a conducting medium which is perfectly neutral to the muscle, and amalgamated zinc in solution of sulphate of zinc does not become polarised.

869. **Currents of muscle at rest.**—In describing these experiments the surface of the muscle is called the *natural longitudinal section*; the tendon, the *natural transverse section*; and the surfaces obtained by cutting the muscle longitudinally or transversely are respectively the *artificial longitudinal* and *artificial transverse sections.*

If a living irritable muscle be removed from a recently killed frog, and the clay of one electrode be placed in contact with its surface, and of the other with its tendon, the galvanometer will indicate a current from the former to the latter; showing, therefore, that the surface of the muscle is positive with respect to the tendon. By varying the position of the electrodes, and making various artificial sections, it is found—

1. That any longitudinal section is positive to any transverse.
2. That any point of a longitudinal section nearer the middle of the muscle is positive to any other point of the same section farther from the centre.
3. In any artificial transverse section any point nearer the periphery is positive to one nearer the centre.
4. The current obtained between two points in a longitudinal or in a transverse section is always much more feeble than that obtained between two different sections.
5. No current is obtained if two points of the same section equidistant from its centre be taken.
6. To obtain these currents it is not necessary to employ a whole muscle, or a considerable part of one, but the smallest fragment that can be experimented with is sufficient.
7. If a muscle be cut straight across, the most powerful current is that from the centre of the natural longitudinal section to the centre of the artificial transverse; but if the muscle be cut across obliquely, as in fig. 735, the most positive point is moved from *c* towards *b*, and the most negative from *d* towards *a* ('*Currents of inclination*').

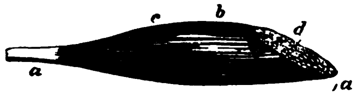


Fig. 735.

To explain the existence and relations of these muscular currents, it may be supposed that each muscle is made up of regularly disposed electromotor elements, which may be regarded as cylinders whose axis is parallel to that of the muscle, and whose sides are charged with positive and their ends with negative electricity; and, further, that all are suspended and enveloped in a conducting medium. In such a case (fig. 736), it is clear that throughout most of the muscle the positive electricities of the opposed surfaces would neutralise one another, as would also the negative charges of the ends of the cylinders; so that, so long as the muscle was intact, only the charges at its sides and ends would be left free to manifest themselves by the production of electromotive phenomena; the whole muscle being enveloped in a conducting stratum, a current would constantly be passing from the longitudinal to the transverse section, and, a part of this being led off by the wire circuit, would manifest itself in the galvanometer.

This theory also explains the currents between two different points on the same section; the positive charge at *b*, for instance (fig. 736), would have more resistance to overcome in getting to the transverse section than that at *d*, therefore it has a higher tension; and if *b* and *d* are connected by the electrodes, *b* will be found positive to *d*, and a current will pass from the former to the latter.

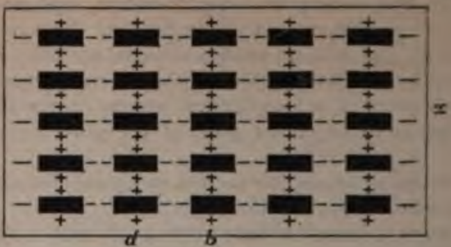


Fig. 736.

What are called *currents of inclination* are also explicable on the above hypothesis, for the oblique section can be represented as a number of elements arranged as in fig. 737, so that both the longitudinal surfaces and the ends of the cylinders are laid bare, and it can thus be regarded as a sort of oblique pile whose positive pole is towards *b* and its negative at *a*, and whose current adds itself algebraically to the ordinary current and displaces its poles as above mentioned.

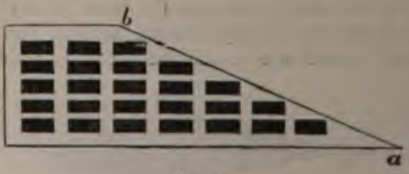


Fig. 737.

A perfectly fresh muscle, very carefully removed, with the least possible contact with foreign matters, sometimes gives almost no current between its different natural sections, and the current always becomes more marked after the muscle has been exposed a short time; nevertheless, the phenomena are vital, for the currents disappear completely with the life of the muscle, sometimes becoming first irregular or even reversed in direction.

870. **Rheoscopic frog. Contraction without metals.**—The existence of the muscular currents can be manifested without a galvanometer, by using another muscle as a galvanoscope. Thus if the nerve of one living muscle be dropped suddenly on another living muscle, so as to come in contact with its longitudinal and transverse sections, a contraction of the first muscle will occur, due to the stimulation of its nerve by the passage through it of the electric current derived from the surface of the second.

871. **Currents in active muscle.**—When a muscle is made to contract there occurs a sudden diminution of its natural electric current, as in-

dicated by the galvanometer. This is so instantaneous that, in the case of a single muscular contraction it does not overcome the inertia of the needle of the galvanometer; but if the contractions be made to succeed one another very rapidly—that is, if the muscle be *tetanised* (760)—then the needle swings steadily back towards zero from the position in which the current of the resting muscle had kept it, often gaining such momentum in the swing as to pass beyond the zero point, but soon reverting to some point between zero and its original position.

The negative variation in the case of a simple muscular contraction can, however, be made manifest by using another muscle as a rheoscope; if the nerve of this second muscle be laid over the first muscle in such a position that the muscular current passes through it, and the first muscle be then made to contract, the sudden alteration in the intensity of its current stimulates the nerve laid on it (760), and so causes a contraction of the muscle to which the latter belongs.

The same phenomena can be demonstrated in the muscles of warm-blooded animals; but with less ease, on account of the difficulty of keeping them alive after they are laid bare or removed from the body. Experiments made by placing electrodes outside the skin, or passing them through it, are inexact and unsatisfactory.

872. **Electric currents in nerve.**—From nerves the same electromotor indications can be obtained as from muscles; at least, as far as their smaller size will permit; the currents are more feeble than the muscular ones, but can be demonstrated by the galvanometer in a similar way. Negative variation has been proved to occur in active nerve as in active muscle. The effect of a constant current passed through one part of a nerve on the amount of the normal nerve current, measured at another part, has already been described (Chap. III., Electrotonus).

873. **Electrical fish.**—Electrical fish are those fish which have the remarkable property of giving, when touched, shocks like those of the Leyden jar. Of these fish there are several species, the best known of which are the torpedo, the gymnotus, and the silurus. The torpedo, which is very common in the Mediterranean, has been carefully studied by MM. Becquerel and Breschet in France, and by M. Matteucci in Italy. The gymnotus has been investigated by Humboldt and Bonpland in South America, and in England by Faraday, who had the opportunity of examining live specimens.

The shock which they give serves both as a means of offence and of defence. It is purely voluntary, and becomes gradually weaker as it is repeated and as these animals lose their vitality, for the electrical action soon exhausts them materially.

The shock is very violent. According to Faraday the shock which the gymnotus gives is equal to that of a battery of 15 jars exposing a coating of 25 square feet, which explains how it is that horses frequently give way under the repeated attacks of the gymnotus.

Numerous experiments show that these shocks are due to ordinary electricity, For if, touching with one hand the back of the animal, the belly is touched with the other, or with a metal rod, a violent shock is felt in the wrists and arms : while no shock is felt if the animal is touched with an insulating body. Further, when the back is connected with one end of a galvanometer wire and the belly with the other, at each discharge the needle is deflected, but immediately returns to zero, which shows that there is an instantaneous current ; and, moreover, the direction of the needle shows that the current goes from the back to the belly of the fish. Lastly, if the current of a torpedo be passed through a helix, in the centre of which is a small steel bar, the latter is magnetised by the passage of the discharge.

By means of the galvanometer, Matteucci has established the following facts :

1. When a torpedo is lively, it a shock in any part of its body; but as its vitality diminishes, th which it can give a shock are nearer the organ which is the se levelopment of electricity.

2. Any point of the back is a itive as compared with the corresponding point of the belly.

3. Of any two points at diffe nces from the electrical organ, the nearest always plays the p tive pole, and the furthest that of negative pole. With the bel erse is the case.

The organ where the electricity is produced in the torpedo is double, and formed of two parts symmetrically situated on the two sides of the head, and attached to the skull bone by the internal face. Each part consists of nearly parallel lamellæ of connective tissue inclosing small chambers, in which lie the so-called *electrical plates*, each of which has a final nerve ramification distributed on one of its faces. This face, on which the nerve ends, is turned the same way in all the plates, and when the discharge takes place is always negative to the other.

Matteucci investigated the influence of the brain on the discharge. For this purpose he laid bare the brain of a living torpedo, and found that the first three lobes could be irritated without the discharge being produced, and that when they were removed the animal still possessed the faculty of giving a shock. The fourth lobe, on the contrary, could not be irritated without an immediate production of the discharge ; but if it was removed, all disengagement of electricity disappeared, even if the other lobes remained untouched. Hence it would appear that the primary source of the electricity elaborated is the fourth lobe, whence it is transmitted by means of the nerves to the two organs described above, which act as multipliers. In the silurus the head appears also to be the seat of the electricity ; but in the gymnotus it is found in the tail.

874. **Application of electricity to medicine.**—The first applications of electricity to medicine date from the discovery of the Leyden jar. Nollet and Boze appear to have been the first who thought of the application, and soon the spark and electrical frictions became a universal panacea : but it must be admitted that subsequent trials did not come up to the hopes of the experimentalists.

After the discovery of dynamic electricity Galvani proposed its application to medicine : since which time many physicists and physiologists have been engaged upon this subject, and yet there is still much uncertainty as to the real effects of electricity, the cases in which it is to be applied, and the best mode of applying it. Practical men prefer the use of currents to that of statical electricity, and, except in a few cases, discontinuous to continuous currents. There is, finally, a choice between the currents of the battery and those of induction currents; further, the effects of the latter differ, according as induction currents of the first or second order are used.

In fact, since induction currents, although very intense, have a very feeble chemical action, it follows that when they traverse the organs, they do not produce the chemical effects of the current of the battery, and hence do not tend to produce the same disorganisation. Further, in electrifying the muscles of the face, induction currents are to be preferred, for Dr. Duchenne has found that these currents only act feebly on the retina, while the currents of the battery act energetically on this organ, and may affect it dangerously, as serious accidents have shown. There is a difference in the action of induced currents of different orders: for while the primary induced current causes lively muscular actions, but has little action on the cutaneous sensibility, the secondary induced current, on the contrary, increases the cutaneous sensibility to such a point, that its use ought to be proscribed to persons whose skin is very irritable.

Hence electrical currents should not be applied in therapeutics without a thorough knowledge of their various properties. They ought to be used with great prudence, for their continued action may produce serious accidents. Matteucci, in his lectures on the physical phenomena of living bodies, expresses himself as follows: 'In commencing, a feeble current must always be used. This precaution now seems to me the more important, as I did not think it so before seeing a paralytic person seized with almost tetanic convulsions under the action of a current formed of a single element. Take care not to continue the application too long, especially if the current is energetic. Rather apply a frequently-interrupted current than a continuous one, especially if it be strong; but after 20 or 30 shocks at most, let the patient take a few moments' rest.'

Of late years, however, feeble continuous currents have come more into use. They are frequently of great service when applied skilfully so as to throw the nerves of the diseased part into a state of cathelectrotonus or analectrotonus, according to the end which is wished for in any given case.

ELEMENTARY OUTLINES
OF
METEOROLOGY [illegible] CLIMATOLOGY.

ME[illegible]Y.

875. **Meteorology.**—The pl[illegible]which are produced in the atmosphere are called *meteors*; [illegible]*rology* is that part of physics which is concerned with the study of these phenomena.

A distinction is made between *aerial* meteors, such as winds, and hurricanes, and whirlwinds; *aqueous* meteors, comprising fogs, clouds, rain, dew, snow, and hail; and *luminous* meteors, as lightning, the rainbow, the aurora borealis.

Aerial Meteors.

876. **Direction and velocity of winds.**—*Winds* are currents moving in the atmosphere with variable directions and velocities. There are eight principal directions in which they blow—***north***, ***north-east***, ***east***, ***south-east***, ***south***, ***south-west***, ***west***, and ***north-west***. Mariners further divide each of the distances between these eight directions into four others, making in all 32 directions, which are called ***points*** or ***rhumbs***. A figure, of these 32 rhumbs on a circle, in the form of a star, is known as the *mariner's card*.

The direction of the wind is determined by means of vanes, and its velocity by means of the *anemometer*. There are several forms of this instrument; the most usual consists of a small vane with fans, which the wind turns; the velocity is deduced from the number of turns made in a given time, which is measured by means of an endless screw and wheel-work. In our climate the mean velocity is from 18 to 20 feet in a second. With a velocity of 6 or 7 feet, the wind is moderate; with 30 or 35 feet, it is fresh; with 60 or 70 feet, it is strong; with a velocity of 85 to 90 feet, it is a tempest; and, from 90 to 120, it is a hurricane.

We have but few experimental results as to the law of the intensity of the force which wind exerts on surfaces exposed to its action. Smeaton gives a table compiled by Rouse from a considerable number of facts and experiments; he observes that these experiments do not deserve as much confidence for velocities above as for velocities below 50 miles an hour. The numerical values for the pressures given, this table seems to have been calculated on the supposition that the pressure is proportional to the square of the velocity of the wind; they are approximately given by the formula

$$f = 0{\cdot}002214\ V^2,$$

where V, being the velocity of the wind in feet per second, f is the pressure in pounds per square foot.

877. **Causes of winds.**—Winds are produced by a disturbance of the equilibrium in some part of the atmosphere; a disturbance always resulting from a difference in temperature between adjacent countries. Thus, if the temperature of a certain extent of ground becomes higher, the air in contact with it becomes heated, it expands and rises towards the higher regions of the atmosphere; whence it flows, producing winds which blow from hot to cold countries. But at the same time the equilibrium is destroyed at the surface of the earth, for the barometric pressure on the colder adjacent parts is greater than on that which has been heated, and hence a current will be produced with a velocity dependent on the difference between these pressures; thus two distinct winds will be produced, an upper one setting *outwards* from the heated region, and a lower one setting *inwards* towards it.

878. **Regular, periodical, and variable winds.**—According to the more or less constant directions in which winds blow, they may be classed as regular, periodical, and variable winds.

i. *Regular winds* are those which blow all the year through in a virtually constant direction. These winds, which are also known as the *trade winds*, are uninterruptedly observed far from the land in equatorial regions, blowing from the north-east to the south-west in the northern hemisphere, and from the south-east to the north-west in the southern hemisphere. They prevail on the two sides of the equator as far as 30° of latitude, and they blow in the same direction as the apparent motion of the sun—that is, from east to west.

The air above the equator being gradually heated, rises as the sun passes round from east to west, and its place is supplied by the colder air from the north or south. The direction of the wind, however, is modified by this fact, that the velocity which this colder air has derived from the rotation of the earth—namely, the velocity of the surface of the earth at the point from which it started—is less than the velocity of the surface of the earth at the point at which it has now arrived; hence the currents acquire, in reference to the equator, the constant direction which constitutes the trade winds.

ii. *Periodical winds* are those which blow regularly in the same direction at the same seasons, and at the same hours of the day: the monsoon, simoom, and the land and sea breeze are examples of this class. The name *monsoon* is given to winds which blow for six months in one direction and for six months in another. They are principally observed in the Red Sea and in the Arabian Gulf, in the Bay of Bengal and in the Chinese Sea. These winds blow towards the continents in summer, and in a contrary direction in winter. The *simoom* is a hot wind which blows over the deserts of Asia and Africa, and which is characterised by its high temperature and by the sands which it raises in the atmosphere and carries with it. During the prevalence of this wind the air is darkened, the skin feels dry, the respiration is accelerated, and a burning thirst is experienced.

This wind is known under the name of *sirocco* in Italy and Algiers, where it blows from the great desert of Sahara. In Egypt, where it prevails from the end of April to June, it is called *kamsin*. The natives of Africa, in order to protect themselves from the effects of the too rapid perspiration occasioned by this wind, cover themselves with fatty substances.

The *land* and *sea breeze* is a h blows on the sea coast during the day from the sea towards t and during the night from the land to the sea. For during the land becomes more heated than the sea, in consequence of its l cific heat and greater conductivity, and hence as the super air becomes more heated than that upon the sea, it ascends a aced by a current of colder and denser air flowing from the sea the land. During the night the land cools more rapidly than the l hence the same phenomenon is produced in a contrary direction. The sea breeze commences after sunrise, increases to three o'clock in the afternoon, decreases towards evening, and is changed into a land breeze after sunset. These winds are only perceived at a slight distance from the shores. They are regular in the tropics, but less so in our climates; and traces of them are seen as far as the coasts of Greenland. The proximity of mountains also gives rise to periodical daily breezes.

iii. *Variable winds* are those which blow sometimes in one direction and sometimes in another, alternately, without being subject to any law. In mean latitudes the direction of the winds is very variable; towards the poles this irregularity increases, and under the arctic zone the winds frequently blow from several points of the horizon at once. On the other hand, in approaching the torrid zone, they become more regular. The south-west wind prevails in the north of France, in England, and in Germany; in the south of France the direction inclines towards the north, and in Spain and Italy the north wind predominates.

879. **Law of the rotation of winds.**—Spite of the great irregularity which characterises the direction of the winds in our latitude, it has been ascertained that the wind has a preponderating tendency to veer round according to the sun's motion—that is, to pass from north, through north-east, east, south-east to south, and so on round in the same direction from west to north; that it often makes a complete circuit in that direction, or more than one in succession, occupying many days in doing so, but that it rarely veers, and very rarely or never makes a complete circuit in the opposite direction. This course of the winds is most regularly observed in winter. According to Leverrier, the displacement of the north-east by the south-west wind arises from the occurrence of a whirlwind formed upon the Gulf-stream.

For a station in south latitude a contrary law of rotation prevails.

This law, though more or less suspected for a long time, was first formally enunciated and explained by Dove, and is known as *Dove's law of rotation of winds*.

880. **Fogs and mists.**—When aqueous vapours rising from a vessel of boiling water diffuse in the colder air, they are condensed; a sort of cloud is formed which consists of a number of small hollow vesicles of water, which remain suspended in the air. These are usually spoken of as vapours, yet they are not so, at any rate not in the physical sense of the word; for they are partially condensed vapours.

When this condensation of aqueous vapours is not occasioned by contact with cold solid bodies, but takes place throughout large spaces of the atmosphere, they constitute *fogs* or *mists*, which, in fact, are nothing more than the appearance seen over a vessel of hot water.

A chief cause of fogs consists in the moist soil being at a higher temperature than the air. The vapours which then ascend condense and become visible. In all cases, however, the air must have reached its point of saturation before condensation takes place. Fogs may also be produced when a current of hot and moist air passes over a river at a lower temperature than its own, for then the air being cooled, as soon as it is saturated, the excess of vapour present is condensed.

The distinction between mists and fogs is one of degree rather than of kind. A fog is a very thick mist.

881. **Clouds.**—*Clouds* are masses of vapour, condensed into little drops or vesicles of extreme minuteness, like fogs; from which they only differ in occupying the higher regions of the atmosphere; they always result from the condensation of vapours which rise from the earth. According

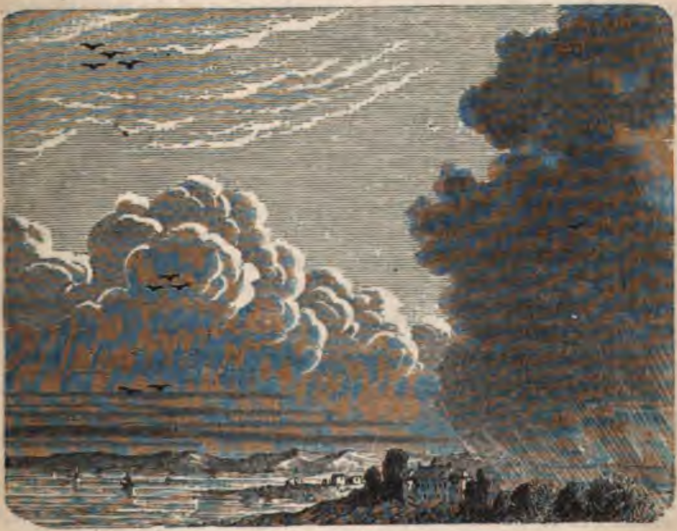


Fig. 738.

to their appearance, they have been divided by Howard into four principal kinds : the *nimbus*, the *stratus*, the *cumulus*, and the *cirrus*. These four kinds are represented in fig. 738, and are designated respectively by one, two, three, and four birds on the wing.

The *cirrus* consist of small whitish clouds, which have a fibrous or wispy appearance, and occupy the highest regions of the atmosphere. The name of *mares' tails*, by which they are generally known, well describes their appearance. From the low temperature of the spaces which they occupy, it is more than probable that cirrus clouds consist of frozen particles ; and hence it is that haloes, coronæ, and other optical appearances, produced by refraction and reflection from ice crystals, appear almost always in these clouds and their derivatives. Their appearance often precedes a change of weather.

The *cumulus* are rounded spherical forms which look like mountains piled one on the other. They are more frequent in summer than in winter, and after being formed in the morning, they generally disappear towards evening. If, on the contrary, they become more numerous, and especially if surmounted by cirrus clouds, rain or storms may be expected.

Stratus clouds consist of very large and continuous horizontal sheets, which chiefly form at sunset, and disappear at sunrise. They are frequent in autumn and unusual in spring time, and are lower than the preceding.

The *nimbus*, or rain clouds, which are sometimes classed as one of the fundamental varieties, are properly a combination of the three preceding kinds. They affect no particular form, and are solely distinguished by a uniform grey tint, and by fringed edges. They are indicated on the right of the figure by the presence of one bird.

The fundamental forms pass into one another in the most varied manner; Howard has classed these traditional forms as *cirro-cumulus*, *cirro-stratus*, and *cumulo-stratus*, and it is often very difficult to tell from the appearance of a cloud, which type it most resembles. The cirro-cumulus is most characteristically known as a 'mackerel sky ;' it consists of small roundish masses, disposed with more or less irregularity and connection. It is frequent in summer, and attendant on warm and dry weather. *Cirro-stratus* appears to result from the subsidence of the fibres of cirrus to a horizontal position, at the same time approaching laterally. The form and relative position when seen in the distance frequently give the idea of shoals of fish. The tendency of *cumulo-stratus* is to spread, settle down into the *nimbus*, and finally fall as rain.

The height of clouds varies greatly ; in the mean it is from 1,300 to 1,500 yards in winter, and from 3,300 to 4,400 yards in summer. But they often exist at greater heights ; Gay-Lussac, in his balloon ascent, at a height of 7,650 yards, observed cirrus-clouds above him, which appeared still to be at a considerable height. In Ethiopia, M. d'Abbadie observed storm clouds whose height was only 230 yards above the ground.

In order to explain the suspension of clouds in the atmosphere, Halley first proposed the hypothesis of vesicular vapours. He supposed that clouds are formed of an infinity of extremely minute vesicles, hollow, like soap bubbles filled with air, which is hotter than the surrounding air; so that these vesicles float in the air like so many small balloons. This theory, which was first propounded by Saussure, has been defended by Kratzenstein, subsequently by Bravais and most physicists; it has, however, been combated by Desagueliers, and afterwards by Monge, and has at present many opponents. These latter assume that clouds and fogs consist of extremely minute droplets of water, which are retained in the atmosphere by the ascensional force of currents of hot air, just as light powders are raised by the wind. Ordinarily, clouds do not appear to descend, but this absence of downward motion is only apparent. In fact, clouds do usually fall slowly, but then the lower part is continually dissipated on coming in contact with the lower and more heated layers; at the same time the upper part is always increasing from the condensation of new vapours; so that from these two actions clouds appear to retain the same height.

882. **Formation of clouds.** — Many causes may concur in the formation of clouds. i. The low temperature of the higher region of the atmosphere. For, owing to solar radiation, vapours are constantly disengaged from the earth and from the waters, which from their elastic force and lower density rise in the atmosphere; meeting there continually colder and colder layers of air, they sink to the point of saturation, and then condensing in infinitely small droplets, they give rise to clouds.

ii. The hot and moist currents of air rising during the day undergo a gradually feebler pressure, and thus is produced an expansion which is a source of intense cold, and produces a condensation of vapour. Hence it is that high mountains, stopping the aerial currents, and forcing them to rise, are an abundant source of rain.

iii. A hot, moist current of air mixing with a colder current, undergoes a cooling, which brings about a condensation of the vapour. Thus the hot and moist winds of the south and south-west, mixing with the colder air of our latitude, give rain. The winds of the north and north-east tend also, in mixing with our atmosphere, to condense the vapours; but as these winds, owing to their low temperature, are very dry, the mixture rarely attains saturation, and generally gives no rain.

The formation of clouds is thus explained by Hutton. The tension of aqueous vapour, and therewith the quantity present in a given space when saturated, diminishes according to a geometric progression, while the temperature falls in arithmetical progression, and therefore the elasticity of the vapour present at any time is reduced by a fall of temperature more rapidly than in direct proportion to the fall. Hence if a current of warm air, saturated with aqueous vapour, meet a current of cold air also saturated, the air acquires the mean temperature of the two, but can only retain a portion of the vapour in the invisible condition, and a cloud or mist is formed. Thus suppose a cubic meter of air at 10° C. mixes with a cubic meter of air at 20° C., and that they are respectively saturated with aqueous vapour. By formula (370) it is easily calculated that the weight of water contained in the cubic metre of air at 10° C. is 9·397 grammes, and in that at 20° C. is 17·632 grammes, or 27·029 grammes in all. When mixed they produce two cubic metres of air at 15° C.; but as the weight of water required to saturate this is only $2 \times 12·8 = 25·6$ grammes, the excess, 1·429 grammes, will be deposited in the form of mist or clouds.

883. **Rain.**—When by the constant condensation of aqueous vapour the individual vapour vesicles become larger and heavier, and when finally individual vesicles unite, they form regular drops, which fall as *rain.*

The quantity of rain which falls annually in any given place, or the annual rainfall, is measured by means of a *rain gauge* or *pluviometer.* Ordinarily it consists of a cylindrical vessel M (figs. 739 and 740), closed at the top by a funnel-shaped lid, in which there is a very small hole, through which the rain falls. At the bottom of the vessel is a glass tube, A, in which the water rises to the same height as inside the rain gauge, and is measured by a scale on the side, as shown in the figures.

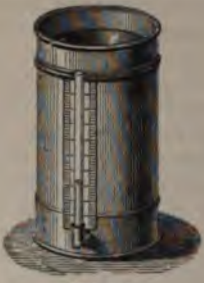


Fig. 739.

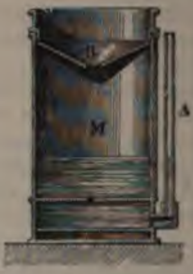


Fig. 740.

The apparatus being placed in an exposed situation, if at the end of a month the height of water in the tube is two inches for example, it shows that the water has attained this height in the vessel; and, consequently, that a layer of two inches in depth expresses the quantity of rain which this extent of surface has received.

It has been noticed that the quantity of rain indicated by the rain gauge is greater as this instrument is nearer the ground. This has been ascribed to the fact that the rain-drops, which are generally colder than the layers of air which they traverse, condense the vapour in these layers, and, therefore, constantly increase in volume. Hence more rain falls on the surface of the ground than at a certain height. But it has been objected that the excess of the quantity of rain which falls, over that at a certain height, is six or seven times that which could arise from condensation, even during the whole course of the rain-drops from the clouds to the earth. The difference must, therefore, be ascribed to purely local causes, and it is now assumed that the difference arises from eddies produced in the air about the rain gauge, which are more perceptible as it is higher above the ground; as these eddies disperse the drops which would otherwise fall into the instrument, they diminish the quantity of water which it receives.

In any case it is clear that if rain-drops traverse moist air, they will from their temperature condense vapour and increase in volume. If, on the contrary, they traverse dry air, the drops tend to vaporise, and less rain falls than at a certain height; it might even happen that the rain did not reach the earth.

Many local circumstances may affect the quantity of rain which falls in different countries; but, other things being equal, most rain falls in hot climates, for there the vaporisation is most abundant. The rain-fall decreases, in fact, from the equator to the poles. At London it is 23·5 inches; at Bordeaux it is 25·8; at Madeira it is 27·7; at Havannah it is 91·2, and at St. Domingo it is 107·6. The quantity varies with the seasons; in Paris, in winter, it is 4·2 inches; in spring 6·9; in summer 6·3, and in autumn 4·8 inches. The heaviest annual rain-fall at any place in the globe is on the Khasia Hills in Bengal, where it is 600 inches; of which 500 inches fall in seven months.

The driest recorded place in England is Lincoln, where the mean rainfall is 20 inches, and the wettest is Stye, at the head of Borrowdale in Cumberland, where it amounts to 165 inches.

An inch of rain on a square yard of surface expresses a fall of 46·74 pounds, or 4·67 gallons. On an acre it corresponds to 22,622 gallons, or 100·9935 tons. 100 tons per inch per acre is a ready way of remembering this.

884. **Waterspouts.**—These are masses of vapour suspended in the lower layers of the atmosphere which they traverse, and endowed with a gyratory motion rapid enough to uproot trees, upset houses, and break and destroy everything with which they come in contact.

These meteors, which are generally accompanied by hail and rain, often emit lightning and thunder, producing the sound of carriages rolling over a stony road. Many of them have no gyratory motion, and about a quarter of those observed are produced in a calm atmosphere.

When they take place on the sea they present a curious phenomenon. The water is disturbed, and rises in the form of a cone, while the clouds are depressed in the form of an inverted cone; the two cones then unite and form a continuous column from the sea to the clouds (fig. 741), which are called *waterspouts*. Even, however, on the high seas the water of these waterspouts is never salt, proving that they are formed of condensed vapours, and not of sea water raised by aspiration.

The origin of these is not known. Kæmtz assumes that they are due principally to two opposite winds which pass by the side of each other, or to a very high wind which prevails in the higher regions of the atmosphere. Peltier and many others ascribe to them an electrical origin.

885. **Influence of aqueous vapour on climate.**—One of the most important elements in meteorology is undoubtedly the property possessed by aqueous vapour of powerfully absorbing and radiating heat. The

same physicist who discovered this property (406), has applied it to the explanation of some obscure points in meteorological science, and there can be no doubt that the knowledge of it will gradually lead to a clearer understanding of many inexplicable and apparently capricious meteorological phenomena.

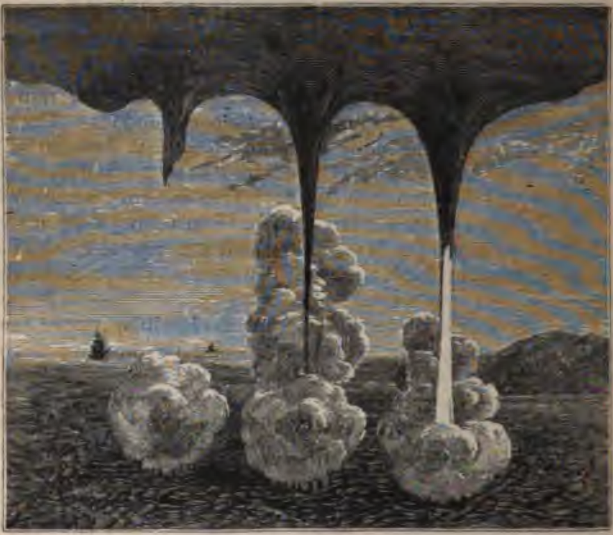


Fig. 741.

Tyndall has established the fact, that in a tube 4 feet long the atmospheric vapour on a day of average dryness absorbs 10 per cent. of obscure heat. With the earth warmed by the sun, as a source, there can be no doubt that at the very least 10 per cent. of its heat is intercepted within 10 feet of the surface. If aqueous vapour be compared atom for atom with air, its power of absorption and radiation is more than 16,000 times that possessed by air. Such facts as these are sufficient to show the importance of the small quantity of this vapour that exists in our atmosphere.

The *radiative* power of aqueous vapour may be the main cause of the torrential rains that occur in the tropics, and also of the formation of cumuli clouds in our own latitudes. This same property probably causes the descent of a very fine rain, called *sérein*, which has more the characteristics of falling dew, as it appears a short time after sunset, when the sky is clear; its production has therefore been attributed to the cold, resulting from the radiation of the air. It is not the air, however, but the aqueous vapour in the air, which by its own radiation chills itself, so that it condenses into *sérein*.

The *absorbent* power of aqueous vapour is even of greater importance. Whenever the air is dry, terrestrial radiation at night is so rapid as to cause intense cold. Thus, in the central parts of Asia, Africa, and Australia, the daily range of the thermometer is enormous; in the interior of the last continent a difference in temperature of no less than 40° C. has been recorded within 24 hours. In India, and even in the Sahara, owing to the copious radiation, ice has been formed at night. But the heat which aqueous vapour absorbs most largely is of the kind emitted from sources of low temperature; it is to a large extent transparent to the heat emitted from the sun, whilst it is almost opaque to the heat radiated from the earth. Consequently, the solar rays penetrate our atmosphere with a loss, as estimated by Pouillet, of only 25 per cent., when directed vertically downwards, but after warming the earth they cannot retraverse the atmosphere. Through thus preventing the escape of terrestrial heat, the aqueous vapour in the air moderates the extreme chilling which is due to the unchecked radiation from the earth, and raises the temperature of that region over which it is spread. Tyndall has thus described the action of this substance:—'Aqueous vapour is a blanket more necessary to the vegetable life of England than clothing is to man. Remove for a single summer night the aqueous vapour from the air which overspreads this country, and every plant capable of being destroyed by a freezing temperature would perish. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost.'

886. **Tyndall's researches.**—Tyndall has recently examined the action of solar and of the electric light on vapours under a great degree of attenuation; and has found that under these circumstances they are decomposed. This new reaction not only puts a most potent agent of chemical decomposition into the hands of chemists, which remains for them to make use of, but it has led Professor Tyndall to important conclusions regarding the origin of the blue colour of the sky, and the polarisation of daylight.

For these experiments he used a glass tube with glass ends, such as he had used for his researches on radiant heat, and which is known as 'the experimental tube.' This could be exhausted and then filled with air charged with the vapours of volatile liquids, by allowing the air to pass through small Wolff bottles containing them. By mixing with different proportions of pure air the air charged with vapour, and by varying the degree of exhaustion, it was possible to have a vapour under any degree of attenuation. It was also possible to fill the tube with the vapour of a liquid alone.

The tube having been filled with air charged with vapours of nitrite of amyle, a somewhat convergent beam from the electric lamp was passed into the tube. For a moment the tube appeared optically empty, but suddenly a shower of liquid spherules was precipitated on the path of the beam forming a luminous white cloud. The nature of the substance thus precipitated was not specially investigated.

This effect was not due to any chemical action between the vapour and the air, for when either dry oxygen or dry hydrogen was used instead of air, or when the vapour was admitted alone, the effect was substantially the same. [illegible]r was it due to any heating effect, for the beam had been previousl[illegible]ed by passing through a solution of alum, and through the thick gla[illegible] the lens. The unsifted beam produced the same effect; the obs[illegible]lorific rays did not seem to interfere with the result.

The s[illegible]ight also affects the decomposition of the nitrite of amyle vapour; [illegible] this decomposition was found to be mainly due to the more refrangi[illegible]ays.

When the electric light, before entering the experimental tube, was made to pass through a layer of the liquid nitrite of amyle an eighth of an inch in thickness, the luminous effect was not appreciably diminished, but the chemical action was almost entirely stopped. Thus that special constituent of the luminous [illegible]hich effects the decomposition of the vapour is absorbed [illegible] The liquid nitrite of amyle is probably decomposed by [illegible]t; [illegible]decomposition, if it take place at all, is far less rapid and distin[illegible]at of the vapour. The circumstance that the absorption is th[illegible]whether the nitrite is in the liquid or in the vaporous state, is co[illegible] by Tyndall as a proof that the absorption is not the act of the [illegible] as a whole, but that it is atomic, that is, that it is to the atoms th[illegible]culiar rate of vibration is transferred, which brings about the [illegible]ition of the body.

Besides nitrite of amyle, the vapour of a number of other substances was examined, such, for example, as benzole, iodide of allyle, bisulphide of carbon. By varying the nature of the vapour, the shape of a cloud could be greatly varied, and in many cases presented the most fantastic and beautiful forms.

It was also found that a vapour which when alone resists the action of light, may, by being associated with another gas or vapour, exhibit a vigorous or even violent action.

Thus, when the tube was filled with atmospheric air, mixed with nitrite of butyle vapour, the electric light produced very little effect. But with half an atmosphere of this mixture, and half an atmosphere of air which had passed through hydrochloric acid, the action of the light was almost instantaneous. In another case mixed air and nitrite of butyle vapour was passed into the tube so as to depress the barometer the $\frac{1}{10}$ of an inch; that is, the mixed air and vapour were under a pressure of $\frac{1}{300}$ of an atmosphere. Air passed through solution of hydrochloric acid was introduced until the pressure was 3 inches. The condensed beam passed through for some time without change, but afterwards a superbly blue cloud was formed.

In cases where the vapours are under a sufficient degree of attenuation, whatever otherwise be their nature, the visible action commences with the formation of a *blue cloud*. The term cloud, however, must not be understood in its ordinary sense: the blue cloud is invisible in ordinary daylight, and to be seen must be surrounded by darkness, *it alone* being illuminated by a powerful beam of light. The blue cloud differs in many important particulars from the finest ordinary clouds, and may be conceived to occupy an intermediate position between these clouds and true cloudless vapour.

By graduating the quantity of vapour, the precipitation may be obtained of any required degree of fineness: forming other particles distinguishable by the naked eye, or particles beyond the reach of the highest microscopic power. There is no reason to doubt that particles may be thus obtained whose wave-length is but a very small fraction of the length of a wave of violet light.

The case is similar to that of carbonic acid gas, which, diffused in the atmosphere, resists the decomposing action of solar light, but when in contiguity with the chlorophyle in the leaves of plants is decomposed.

When the blue cloud produced in these experiments was examined by any polarising arrangement, the light emitted laterally from the beam—that is, in a direction at right angles to its axis—was found to be perfectly polarised. This phenomenon was observed in its greatest perfection the more perfect the blue of the sky. It is produced by any particles, provided they are sufficiently fine.

This is quite analogous to the light of the blue sky. When this is examined by a Nicol's prism, or any other analyser, it is found that the light, emitted at right angles to the path of the sun's rays, is polarised.

These two phenomena, the fundamental blue, and the polarisation of the sky light, which have long been the enigmas of meteorologists, find their definite solution in these experiments. We have only to assume the existence in the higher regions of the atmosphere of excessively fine particles of water; for particles of any kind produce this effect. It is not difficult to conceive the existence of such particles in the higher regions, even on a hot summer's day. For the vapour must there be in a state of extreme attenuation; and inasmuch as the oxygen and hydrogen of the atmosphere behave like a vacuum to radiant heat, the extremely attenuated particles of aqueous vapour are practically in contact with the absolute cold of space.

'Suppose the atmosphere surrounded by an envelope impervious to light, but with an aperture on the sunward side, through which a parallel beam of solar light could enter and traverse the atmosphere. Surrounded on all sides by air not directly illuminated, the track of such a beam would resemble that of the parallel beam of the electric light through an incipient cloud. The sunbeam would be blue, and it would discharge light laterally in the same condition as that discharged by the incipient cloud. The azure revealed by such a beam would be to all intents and purposes a blue cloud.'

887. **Dew. Hoar frost.**—*Dew* is merely aqueous vapour which has condensed on bodies during the night in the form of minute globules. It is occasioned by the chilling which bodies near the surface of the earth experience in consequence of nocturnal radiation. Their temperature having then sunk several degrees below that of the air, it frequently happens, especially in hot seasons, that this temperature is below that at which the atmosphere is saturated. The layer of air which is immediately in contact with the chilled bodies, and which virtually has the same temperature, then deposits a portion of the vapour which it contains; just as when a bottle of cold water is brought into a warm room, it be-

comes covered with moisture, owing to the condensation of aqueous vapour upon it.

According to this theory, which was first propounded by Dr. Wells, all causes which promote the cooling of bodies increase the quantity of dew. These causes are the emissive power of bodies, the state of the sky, and the agitation of the air. Bodies which have a great radiating power more readily become cool, and therefore ought to condense more vapour. In fact, there is generally no deposit of dew on metals, whose radiating power is very small, especially when they are polished; while the ground, sand, glass, and plants, which have a great radiating power, become abundantly covered with dew.

The state of the sky also e eat influence on the formation of dew. If the sky is cloudless, y spaces send to the earth an inappreciable quantity of heat, h radiates very considerably, and therefore becoming very muc here is an abundant deposit of dew. But if there are clouds nperature is far higher than that of the planetary spaces, they turn towards the earth, and as bodies on the surface of the experience a feeble chilling, no deposit of dew takes place.

Wind also influences the quantity of vapour deposited. If it is feeble, it increases it, inasmuch as it renews the air; if it is strong, it diminishes it, as it heats the bodies by contact, and thus does not allow the air time to become cooled. Finally, the deposit of dew is more abundant according as the air is moister, for then it is nearer its point of saturation.

Hoar frost and *rime* are nothing more than dew which has been deposited on bodies cooled below zero, and has therefore become frozen. The flocculent form which the small crystals present, of which rime is formed, shows that the vapours solidify directly without passing through the liquid state. Hoar frost, like dew, is formed on bodies which radiate most, such as the stalks and leaves of vegetables, and is chiefly deposited on the parts turned towards the sky.

888. **Snow. Sleet.**—*Snow* is water solidified in stellate crystals, variously modified, and floating in the atmosphere. These crystals arise from the congelation of the minute vesicles which constitute the clouds, when the temperature of the latter is below zero. They are more regular when formed in a calm atmosphere. Their form may be investigated by collecting them on a black surface, and viewing them through a strong lens. The regularity, and at the same time variety, of their forms are truly beautiful. Fig. 742 shows some of the forms as seen through a microscope.

It snows most in countries near the poles, or which are high above the sea level. Towards the poles, the earth is constantly covered with snow; the same is the case on high mountains, where there are perpetual snows even in equatorial countries.

Sleet is also solidified water, and consists of small icy needles pressed together in a confused manner. Its formation is ascribed to the sudden congelation of the minute globules of the clouds in an agitated atmosphere.

889. **Hail.**—*Hail* is a mass of compact globules of ice of different sizes, which fall in the atmosphere. In our climate hail falls principally during spring and summer, and at the hottest times of the day; it rarely falls at night. The fall of hail is always preceded by a peculiar noise.

Hail is generally the precursor of storms, it rarely accompanies them, and follows them more rarely still. Hail falls from the size of small peas to that of an egg or an orange. The formation of hailstones has never been altogether satisfactorily accounted for; nor more especially their great size. On Volta's theory the hailstones are successively attracted by two clouds charged with opposite electricities; but if the hailstones were thus attracted, it is much more probable that the two clouds would be mutually attracted, and would unite.

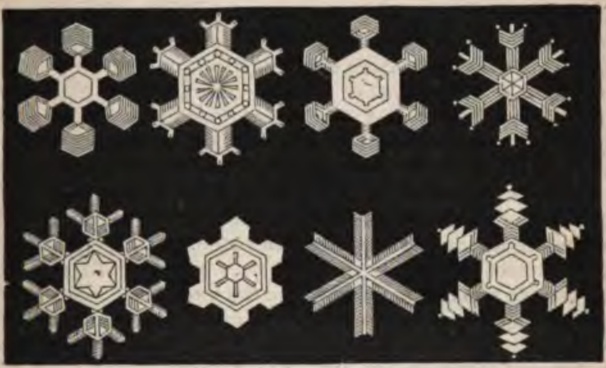


Fig. 742.

890. **Ice. Regelation.**—Ice is nothing more than an aggregate of snow crystals, such as are shown in fig. 742. The transparency of ice is due to the close contact of these crystals, which causes the individual particles to blend into an unbroken mass, and renders the substance *optically*, as well as mechanically, continuous. When large masses of ice slowly melt away, a crystalline form is sometimes seen by the gradual disintegration into rude hexagonal prisms: a similar structure is frequently met with, but in greater perfection, in the ice caves or glaciers of cold regions.

A striking experiment of Tyndall has, however, more clearly revealed the beautiful structure of ice. When a piece of ice is cut parallel to its planes of freezing, and the radiation from any luminous source, as the sun, a glowing fire, a gas or oil flame, is permitted to pass through it, the disintegration of the substance proceeds in a remarkable way. By observing the plate of ice through a lens, numerous small crystals will be seen studding the interior of the block; as the heat continues these crystals expand, and finally assume the shape of six-rayed stars of exquisite beauty.

This is a kind of negative crystallisation, the crystals produced being composed of water, and owe their formation to the molecular disturbance caused by the absorption of heat from the source. Nothing is easier than to reproduce this phenomenon, if care be taken in cutting the ice. The planes of freezing can be found by noting the direction of the bubbles in ice, which are either sparsely arranged in striæ at right angles to the surface, or thickly collected in beds parallel to the surface of the water. A warm and smooth metal plate should be used to level and reduce the ice to a slab not exceeding half an inch in thickness.

A still more important property of ice remains to be noticed. Faraday discovered that when two pieces of melting ice are pressed together they freeze into one at their points o This curious phenomenon is now known under the nam The cause of it has been the subject of much controve plest explanation seems to be that given by its discover es on the exterior of a block of ice are held by cohesion on ; when the temperature is at 0° C., these exterior particles ee are the first to pass into the liquid state, and a film of wate solid. But the particles in the interior of the block are bound des by the solid ice, the force of cohesion is here a maximum, he interior ice has no tendency to pass into a liquid, even when the whole mass is at 0°. If the block be now split in halves, a liquid film instantly covers the fractured surfaces, for the force of cohesion on the broken surfaces has been lessened by the act. By placing the halves together, so that their original position shall be regained, the liquid films on the two fractured surfaces again become bounded by ice on both sides. The film being excessively thin, the force of cohesion is able to act across it; the consequence of this is, the liquid particles pass back into the solid state, and the block is reunited by *regelation*. Not only do ice and ice thus freeze together, but regelation also takes place between moist ice and any nonconducting solid body, as flannel or sawdust; a similar explanation to that just given has been applied here, substituting another solid for the ice on one side. It must be remarked, however, that many eminent philosophers dissent from the explanation here given.

Whatever may be the true cause of regelation, there can be no doubt that this interesting observation of Faraday's explains many natural phenomena. For example, the formation of a snowball depends on the regelation of the snow granules composing it, and as regelation cannot take place at temperatures below 0° C., for then both snow and ice are dry, it is only possible to make a coherent snowball when the snow is melting.

The snow bridges, also, which span wide chasms in the Alps and elsewhere, and over which men can walk in safety, owe their existence to the regelation of gradually accumulating particles of snow.

891. **Glaciers.**—Tyndall has applied this regelating property of ice to the explanation of still grander phenomena—the formation and motion of glaciers, of which the following is a brief description. In elevated regions, what is termed the *snow line* marks the boundary of eternal snow, for above this the heat of summer is unable to melt the winter's snow. By the heat of the sun and the consequent percolation of water

melted from the surface, the lower portions of the snow field are raised to 0° C.; at the same time this part is closely pressed together by the weight of the snow above, regelation therefore sets in, converting the loose snow into a coherent mass.

By increasing pressure the intermingled air which renders snow opaque becomes ejected and transparent; ice then results. Its own gravity, and the pressure from behind, urge downwards the glacier which has thus been formed. In its descent from the mountain the glacier behaves in all respects like a river, passing through narrow gorges with comparative velocity, and then spreading out and moving slowly as its bed widens. Further, just as the central portions of a river move faster than the sides, so Professor Forbes has ascertained that the centre of a glacier moves quicker than its margin, and from the same reason (the difference in the friction encountered) the surface moves more rapidly than the bottom. To explain these facts Forbes assumed ice to be a viscous body capable of flexion, and flowing like lava; but as ice has not the properties of a viscous substance, the now generally accepted explanation of glacier motion is that supplied by the theory of regelation. According to this theory, the brittle ice of the glacier is crushed and broken in its passage through narrow channels, such as that of Trélaporte on Mont Blanc; and then, as it emerges from the gorge which confined it, becomes reunited by virtue of regelation; in this instance forming the well-known Mer de Glace. By numerous experiments Tyndall has established that regelation is adequate to furnish this explanation, and with complete success has artificially imitated, on a small scale, the moulding of glaciers by the crushing and subsequent regelation of ice.

LUMINOUS METEORS.

892. **Atmospheric electricity. Franklin's experiment.**—The most frequent luminous phenomena, and the most remarkable for their effects, are those produced by the free electricity in the atmosphere. The first physicists who observed the electric spark compared it to the gleam of lightning, and its crackling to the sound of thunder. But Franklin, by the aid of powerful electrical batteries, first established a complete parallel between lightning and electricity; and he indicated, in a memoir published in 1749, the experiments necessary to attract electricity from the clouds by means of pointed rods. The experiment was tried by Dalibard in France; and Franklin, pending the erection of a pointed rod on a spire in Philadelphia, had the happy idea of flying a kite, provided with a metallic point, which could reach the higher regions of the atmosphere. In June 1752, during stormy weather, he flew the kite in a field near Philadelphia. The kite was flown with ordinary pack-thread, at the end of which Franklin attached a key, and to the key a silk cord, in order to insulate the apparatus; he then fixed the silk cord to a tree, and having presented his hand to the key, at first he obtained no spark. He was beginning to despair of success, when, rain having fallen, the cord became a good conductor, and a spark passed. Franklin, in his

letters, de his emotion on witnessing the success of the experiment as being so g that he could not refrain from tears.

Franklin, who had discovered the power of points (680), but who did not understand its explanation, imagined that the kite withdrew from the cloud its electricity ; it is, in fact, a simple case of induction, and depends on the inductive action which the thunder-cloud exerts upon the kite and the cord.

893. **Apparatus to investigate the electricity of the atmosphere.**—The apparatus used to ascertain the presence of electricity in the atmosphere are : the electroscope, either with pith balls, straw, or gold leaf; the apparatus first used by Dalil which consisted of an insulated iron rod, 36 yards in height ; ar arged into the atmosphere, and even kites and captive balloons.

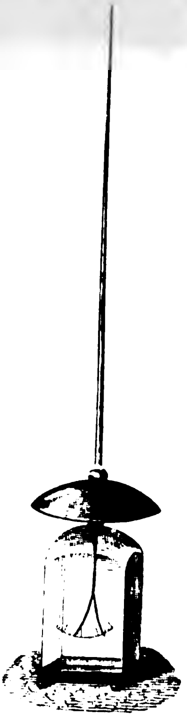


Fig. 743.

To observe the electricity in fi r, when the tension is generally small, an electrometer is used, a by Saussure for this kind of investigation. n electroscope similar to that already des it the rod to which the gold leaves are fi mounted by a conductor 2 feet in length, an nating either in a knob or a point (fig. 743). To protect the apparatus against rain, it is covered with a metallic shield 4 inches in diameter. The glass case is square, instead of being round, and a divided scale on its inside face indicates the divergence of the gold leaves or of the straws. This electrometer only gives signs of atmospheric electricity as long as it is raised in the atmosphere, so that it is in layers of air of which the electrical condition is superior to its own.

To ascertain the electricity of the atmosphere, Saussure also used a copper ball, which he projected vertically with his hand. This ball was fixed to one end of a metallic wire, the other end of which was attached to a ring, which could glide along the conductor of the electrometer. From the divergence of the straws, or of the gold leaves, the electrical condition of the air at the height which the ball attained could be determined. M. Becquerel, in experiments made on the St. Bernard, improved Saussure's apparatus, by substituting for the knob an arrow, which was projected into the atmosphere by means of a bow. A gilt silk thread, 88 yards long, was fixed with one end to the arrow, while the other was attached to the stem of an electroscope. Peltier used a gold-leaf electroscope, at the top of which was a somewhat large copper globe. Provided with this instrument, the observer stations himself in a commanding position—it is then quite sufficient to raise the electroscope even a foot or so to obtain signs of electricity.

To observe the electricity of clouds, where the tension is very considerable, use is made of a long bar terminating in a point. This bar, which is insulated with care, is fixed to the summit of a building, and its lower end is connected with an electrometer, or even an electric chimes (fig. 555), which announces the presence of thunder-clouds. As, however, the bar can then give dangerous shocks, a metallic ball must be placed near it, which is well connected with the ground, and which is nearer the bar than the observer himself; so that if a discharge should ensue, it will strike the ball and not the observer. Professor Richmann, of St. Petersburg, was killed in an experiment of this kind, by a discharge which struck him on the forehead.

Sometimes also captive balloons or kites have been used, provided with a point, and connected by means of a gilt cord with an electrometer.

A good collector of atmospheric electricity consists of a fishing-rod with an insulated handle which projects from an upper window. At the summit is a bit of lighted amadou held in a metallic forceps, the smoke of which, being an excellent conductor, conveys the electricity of the air down a wire attached to the rod. A sponge moistened with alcohol, and set on fire, is also an excellent conductor.

A very convenient instrument for investigating atmospheric electricity has been introduced by Sir W. Thomson; it consists of an insulated can of water placed on a table or on a window-sill on the *inside*. The water discharges through a zinc nozzle at the end of a narrow pipe which projects through the partially open window to a distance of two or three feet, with a head of water of about 10 inches, and a discharge so slow that there is no trouble in replenishing the can; the atmospheric electricity is quickly collected and may be examined by connecting the can with any electrometer.

894. **Ordinary electricity of the atmosphere.**—By means of the different apparatus which have been described, it has been found that the presence of electricity in the atmosphere is not confined to stormy weather, but that the atmosphere always contains free electricity, sometimes positive and sometimes negative. When the sky is cloudless, the electricity is always positive, but it varies in intensity with the height of the locality, and with the time of day. The intensity is greatest in the highest and most isolated places. No trace of positive electricity is found n houses, streets, or under trees; in towns positive electricity is most perceptible in large open spaces, on quays, or on bridges. In all cases, positive electricity is only found at a certain height above the ground. On flat land, it only becomes perceptible at a height of 5 feet; above that point it increases according to a law which is not made out, but which seems to depend on the hygrometric state of the air.

At sunrise the free positive electricity is feeble; it increases up to 11 o'clock, according to the season, and then attains its first maximum. It then decreases rapidly until a little before sunset, and then increases ill it reaches its second maximum, a few hours after sunset; the remainder of the night the electricity decreases until sunrise. Thus the greatest amount of electricity is observed when the barometric pressure is greatest. These increasing and decreasing periods, which are observed all the year, are more perceptible when the sky is clearer, and the weather more settled. The positive electricity of fine weather is much stronger in winter than in summer.

In foggy weather the electricity of the air is more strongly positive than at other times. When the sky is clouded, the electricity is sometimes positive and sometimes negative. It often happens that the electricity changes its sign several times in the course of the day, owing to the passage of an electrified cloud. During storms, and when it rains or snows, the atmosphere may be positively electrified one day, and negatively the next, and the num ie two sets of days are virtually equal.

The electricity of the ground h found by Peltier to be always negative, but to different extents, g to the hygrometric state and temperature of the air.

895. **Causes of the atmosphe ricity.**—Many hypotheses have been propounded to explain th of the atmospheric electricity. Some have ascribed it to the fri e air against the ground, some to the vegetation of plants, or tc oration of water. Some, again, have compared the earth to a vast voltaic pile, and others to a thermo-electrical apparatus. Many of these causes may, in fact, concur in producing the phenomena.

Volta first showed that the evaporation of water produced electricity. Pouillet and others have subsequently shown that no electricity is produced by the evaporation of distilled water; but if an alkali or a salt is dissolved, even in small quantity, the vapour is positively and the solution is negatively electrified. The reverse is the case if the water contains acid. Hence it has been assumed that as the waters which exist on the surface of the earth and on the sea always contain salt dissolved, the vapours disengaged ought to be positively and the earth negatively electrified.

The development of electricity by evaporation may be observed by heating strongly a platinum dish, adding to it a small quantity of liquid, and placing it on the upper plate of the condensing electroscope (fig. 563), taking care to connect the lower plate with the ground. When the water of the capsule is evaporated, the connexion with the ground is broken, and the upper plate raised. The gold leaves then diverge if the water contained salts, but remain quiescent if the water was pure.

Reasoning from this experiment, Pouillet has ascribed the development of electricity by evaporation to the separation of particles of water from the substances dissolved; but Reich and Reiss have shown that the electricity disengaged during evaporation could be attributed to the friction which the particles of water carried away in the current of vapour exercise against the sides of the vessel, just as in Armstrong's electrical machine. By a recent series of experiments, Gaugain has arrived at the same result; and thinks it no longer allowable to ascribe the atmospheric electricity to any changes that take place during the tranqui. evaporation of sea water.

In support of the hypothesis which considers the earth as an immense source of voltaic electricity due to chemical actions, Becquerel has recently published numerous experiments to show that when earth and water come in contact, electricity is always produced : the earth taking a considerable excess of positive or negative electricity, and the water a corresponding excess of the opposite electricity, according to the nature of the salts or other compounds which the water held dissolved. This is a general fact which, according to M. Becquerel, is liable to no exception.

Becquerel experimented with an ordinary multiplier, the wire of which was connected with two platinum plates immersed in the pieces of ground, or the water whose electrical condition he wished to investigate. He thus found that when two moist pieces of ground are connected, that which contained the strongest solution took an excess of positive electricity. He found that in the neighbourhood of a river, even at some distance, the land and objects placed on the surface possessed an excess of negative electricity, while the water and the aquatic plants which swam on the surface were charged with positive electricity. But according to the nature of the substances dissolved in the water, different effects were produced. As from Becquerel's experiments, the waters are sometimes positive and sometimes negative, and the earth in a contrary condition, it follows that water in evaporating must constantly send into the atmosphere an excess of positive or negative electricity, while the earth, by the vapours disengaged on its surface, allows an excess of the contrary electricity to escape. Now this excess of electricity ought necessarily to influence the distribution of the electricity in the atmosphere, and may serve to explain how it is that the clouds are sometimes positively and sometimes negatively electrified.

896. **Electricity of clouds.**—In general the clouds are all electrified, sometimes positively and sometimes negatively, and only differ in their greater or less tension. The formation of positive clouds is usually ascribed to the vapours which are disengaged from the ground, and condense in the higher regions. Negative clouds are supposed to result from fogs, which, by their contact with the ground, become charged with negative fluid, which they retain on rising into the atmosphere; or that, separated from the ground by layers of moist air, they have been negatively electrified by induction from the positive clouds, which have repelled into the ground positive electricity.

897. **Lightning.**—This, as is well known, is the dazzling light emitted by the electric spark when it shoots from clouds charged with electricity. In the lower regions of the atmosphere the light is white, but in the higher regions, where the air is more rarefied, it takes a violet tint; as does the spark of the electrical machine in a rarefied medium (724).

The flashes of lightning are sometimes several leagues in length; they generally pass through the atmosphere in a zigzag direction: a phenomenon ascribed to the resistance offered by the air condensed by the passage of a strong discharge. The spark then diverges from a right line, and takes the direction of least resistance. In vacuo electricity passes in a straight line.

Several kinds of lightning flashes may be distinguished—1. the *zigzag* flashes, which move with extreme velocity in the form of a line of fire with sharp outlines, and which entirely resemble the spark of an electrical machine; 2. the *flashes* which, instead of being linear, like the preceding, fill the entire horizon without having any distinct shape. This kind, which is most frequent, appears to be produced in the cloud itself, and to illuminate the mass. According to Kundt the number of sheet discharges are to the zigzag discharges as 11 : 6; and from spectrum observations it would appear [illegible] former are brush discharges between clouds, while the latter [illegible] electrical discharges between the clouds and the earth. Anoth[illegible] is called *heat lightning*, because it illuminates the summer nigh[illegible]ut the presence of any clouds above the horizon, and without [illegible]g any sound. The most probable of the many hypotheses wh[illegible] been proposed to account for its origin, is that which supposes it [illegible]st of ordinary lightning flashes, which strike across the clouds [illegible] distances that the rolling of thunder cannot reach the ear of [illegible]rver. There is further the very unusual phenomenon of *globe lightning*, or the flashes which appear in the form of globes of fire. These, which are sometimes visible for as much as ten seconds, descend from the clouds to the earth with such slowness that the eye can follow them. They often rebound on reaching the ground; at other times they burst and explode with a noise like that of the report of many cannon.

The duration of the light of the first three kinds does not amount to a thousandth of a second, as has been determined by Mr. Wheatstone by means of a rotating wheel, which was turned so rapidly that the spokes were invisible: on illuminating it by the lightning flash, its duration was so short that, whatever the velocity of rotation of the wheel, it appeared quite stationary; that is, its displacement is not perceptible during the time the lightning exists.

898. **Thunder.**—The *thunder* is the violent report which succeeds lightning in stormy weather. The lightning and the thunder are always simultaneous, but an interval of several seconds is always observed between these two phenomena, which arises from the fact that sound only travels at the rate of about 1,100 feet in a second (216), while the passage of light is almost instantaneous. Hence an observer will only hear the noise of thunder five or six seconds, for instance, after the lightning, according as the distance of the thunder-cloud is five or six times 1,100 feet. The noise of thunder arises from the disturbance which the electric discharge produces in the air, and which may be witnessed in Kinnersley's thermometer. Near the place where the lightning strikes, the sound is dry and of short duration. At a greater distance a series of reports are heard in rapid succession. At a still greater distance the noise, feeble at the commencement, changes into a prolonged rolling sound of varying intensity. If the lightning is at a greater distance than 14 or 15 miles, it is no longer heard, for sound is more imperfectly propagated

through air than through solid bodies; hence, there are lightning discharges without thunder; these occur at times when the sky is cloudless.

Some attribute the noise of the rolling of thunder to the reflection of sound from the ground and from the clouds. Others have considered the lightning not as a single discharge, but as a series of discharges, each of which gives rise to a particular sound. But as these partial discharges proceed from points at different distances, and from zones of unequal density, it follows not only that they reach the ear of the observer successively, but that they bring sounds of unequal density, which occasion the duration and inequality of the rolling. The phenomenon has finally been ascribed to the zigzags of lightning themselves, assuming that the air at each salient angle is at its greatest compression, which would produce the unequal intensity of the sound.

899. **Effects of lightning.**—The lightning discharge is the electric discharge which strikes between a thunder-cloud and the ground. The latter, by the induction from the electricity of the cloud, becomes charged with contrary electricity; and when the tendency of the two electricities to combine exceeds the resistance of the air, the spark passes, which is often expressed by saying that a thunder-bolt has fallen. Lightning in general strikes from above, but *ascending lightning* is also sometimes observed; probably this is the case when the clouds being negatively the earth is positively electrified, for all experiments show that at the ordinary pressure the positive fluid passes through the atmosphere more easily than negative electricity.

From the first law of electrical attraction, the discharge ought to fall first on the nearest and best-conducting objects, and, in fact, trees, elevated buildings, metals, are more particularly struck by the discharge. Hence it is imprudent to stand under trees in stormy weather, especially if they are good conductors, such as oaks and elms. But the danger is said not to be the same under resinous trees, such as pines, for they conduct less well.

The effects of lightning are very varied, and of the same kind as those of batteries (720), but of far greater intensity. The lightning discharge kills men and animals, inflames combustible matters, melts metals, breaks bad conductors in pieces. When it penetrates the ground it melts the siliceous substance in its way, and thus produces in the direction of the discharge those remarkable vitrified tubes called *fulgurites*, some of which are as much as 12 yards in length. When it strikes bars of iron, it magnetises them, and often inverts the poles of compass needles.

After the passage of lightning, a highly peculiar odour is generally produced, like that perceived in a room in which an electrical machine is being worked. This odour was first attributed to the formation of an oxygenised compound, to which the name *ozone* was given: but Schönbein, in 1840, has shown that ozone is a peculiar allotrophic modification of oxygen.

900. **Return shock.**—This is a violent and sometimes fatal shock which men and animals experience, even when at a great distance from

the place where the lightning discharge passes. This is caused by inductive action which the thunder cloud exerts on bodies placed wit the sphere of its activity. These bodies are then, like the ground, char with the opposite electricity to that of the cloud; but when the latte discharged by the recombination of its electricity with that of the grou the induction ceases, and the bodies reverting rapidly from the electri state to the neutral state, the concussion in question is produced, the *retu* *shock*. A gradual decomposition and reunion of the electricity produ invisible effects; yet it appears that such disturbances of the electric equilibrium are perceived by nervous persons.

The return shock is always less violent than the direct one; there is n instance of its having produced any inflammation, yet plenty of cases which it has killed both men and animals; in such cases no broke limbs, wounds, or burns, are observed.

The return shock may be imitated by placing a frog near a stron electrical machine in action; at each spark taken from the machine, the frog experiences a smart shock.

901. **Lightning conductor.**—The ordinary form of this instrument is an iron rod, through which passes the electricity of the ground attracted by the opposite electricity of the thunder-clouds. It was invented by Franklin in 1755.

There are two principal parts in a lightning conductor; the rod and the conductor. The *rod* is a pointed bar of iron, fixed vertically to the roof of the edifice to be protected; it is from 6 to 10 feet in height, and its basal section is about 2 or 3 inches in diameter. The conductor is a bar of iron which descends from the bottom of the rod to the ground, which it penetrates to some distance. As, in consequence of their rigidity, iron bars cannot always be well adapted to the exterior of buildings, they are best formed of wire cords, such as are used for rigging and for suspension bridges. In a report made by the Academy of Sciences on the construction of lightning conductors, the use of copper instead of iron wire in these conductors is recommended, inasmuch as copper is a better conductor than iron. The metallic section of the cords ought to be about $\frac{1}{2}$ a square inch, and the individual wires 0·04 to 0·06 inch in diameter; they ought to be twisted in three strands, like an ordinary cord. The point of the lightning conductor ought to be of copper instead of platinum, for the sake of better conductivity. The conductor is usually led into a well, and to conduct it better with the soil it ends in two or three ramifications. If there is no well in the neighbourhood, a hole is dug in the soil to the depth of 6 or 7 yards, and the foot of the conductor having been introduced, the hole is filled with wood-ashes, which conduct very well and preserve the metal from oxidation.

The action of a lightning conductor depends on induction and the power of points (680); when a storm-cloud, positively electrified, for instance, rises in the atmosphere, it acts inductively on the earth, repels the positive and attracts the negative fluid, which accumulates in bodies placed on the surface of the soil, the more abundantly as these bodies are by greater height. The tension is then greatest on the highest bodies, which are therefore most exposed to the electric discharge; but if these bodies are provided with metallic points, like the rods of conductors, the negative fluid, withdrawn from the soil by the influence of the cloud, flows into the atmosphere, and neutralises the positive fluid of the cloud. Hence, not only does a lightning conductor tend to prevent the accumulation of electricity on the surface of the earth, but it also tends to restore the clouds to their natural state, both which concur in preventing lightning discharges. The disengagement of electricity is, however, sometimes so abundant, that the lightning conductor is inadequate to discharge the ground, and the lightning strikes; but the conductor receives the discharge, in consequence of its greater conductivity, and the edifice is preserved.

Experiment has shown that, approximately, a lightning conductor protects a circular space around it, the radius of which is double its height. Thus, a building, 64 yards in length, would be preserved by two rods 8 yards in height, at a distance of 32 yards.

A conductor, to be efficient, ought to satisfy the following conditions: i. the rod ought to be so large as not to be melted if the discharge passes; ii. it ought to terminate in a point to give readier issue to the electricity disengaged from the ground, hence the rod is usually provided with a point of platinum or of gilt copper; iii. the conductor must be continuous from the point to the ground, and the connexion between the rod and the ground must be as intimate as possible; iv. if the building which is provided with a lightning conductor contains metallic surfaces of any extent, such as zinc roofs, metal gutters, or iron work, these ought to be connected with the conductor. If the last two conditions are not fulfilled, there is great danger of *lateral discharges*; that is to say, that the discharge takes place between the conductor and the edifice, and then it only increases the danger.

902. **Rainbow.**—The *rainbow* is a luminous meteor which appears in the clouds opposite the sun when they are resolved into rain. It consists of seven concentric arcs, presenting successively the colours of the solar spectrum. Sometimes only a single bow is perceived, but there are usually two; a lower one, the colours of which are very bright, and an external or *secondary* one, which is paler, and in which the order of the colours is reversed. In the interior rainbow the red is the highest colour; in the other rainbow the violet is. It is seldom that three bows are seen; theoretically a greater number may exist, but their colours are so feeble that they are not perceptible.

The phenomenon of the rainbow is produced by the decomposition of the white light of the sun when it passes into the drops and by its reflection from their inside face. In fact, the same phenomenon is witnessed in dewdrops and in jets of water; in short, wherever solar light passes into drops of water under a certain angle.

The appearance and the extent of the rainbow depend on the position of the observer, and on the height of the sun above the horizon; hence only some of the rays refracted by the rain drops, and reflected in their concavity to the eye of the spectator, are adapted to produce the phenomenon. Those which do so are called *effective rays.*

To explain this let *n* (fig. 744) be a drop of water, into which a solar ray S*a* penetrates. At the point of incidence, *a*, part of the light is reflected from the surface of the liquid; another, entering it, is decomposed and traverses the drop in the direction *ab*. Arrived at *b*, part of the light emerges from the rain drop, the other part is reflected from the concave surface, and tends to emerge at *g*. At this point the light is again partially reflected, the remainder emerges in a direction *g*O, which forms

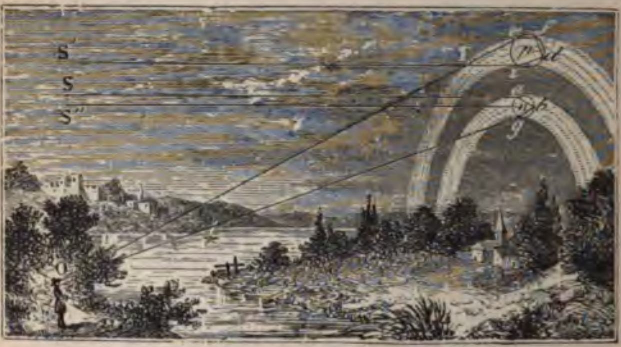


Fig. 744.

with the incident ray, S*a*, an angle, called the *angle of deviation.* It is such rays as *g*O, proceeding from the side next the observer, which produce on the retina the sensation of colours, provided the light is sufficiently intense.

It can be shown mathematically that in the case of a series of rays which impinge on the same drop, and only undergo a reflection in the interior, the angle of deviation increases from the ray S′′*n*, for which it is zero, up to a certain limit, beyond which it decreases, and that near this limit rays passing parallel into a drop of rain, also emerge parallel. From this parallelism a beam of light is produced sufficiently intense to impress the retina; these are the rays which emerge parallel and are efficient.

As the different colours which compose white light are unequally refrangible, the maximum angle of deviation is not the same for all. For red rays the angle of deviation corresponding to the active rays is 42° 2′, and for violet rays it is 40° 17′. Hence, for all drops placed so that rays proceeding from the sun to the drop make, with those proceeding from the drop to the eye, an angle of 42° 2′, this organ will receive the sensation of red light; this will be the case with all drops situated on the circumference of the base of a cone, the summit of which is the spectator's eye; the axis of this cone is parallel to the sun's rays, and the angle formed by the two opposed generating lines is 84° 4′. This explains the formation of the red band in the rainbow: the angle of the cone in the case of the violet band is 80° 34′.

The cones corresponding to each band have a common axis called the *visual axis*. As this right line is parallel to the rays of the sun, it follows that when this axis is on the horizon, the visual axis is itself horizontal, and the rainbow appears as a semicircle. If the sun rises, the visual axis sinks, and with it the rainbow. Lastly, when the sun is at a height of 42° 2′, the arc disappears entirely below the horizon. Hence, the phenomenon of the rainbow never takes place except in the morning and evening.

What has been said refers to the interior arc. The secondary bow is formed by rays which have undergone two reflections, as shown by the ray S′*i dfe*O, in the drop *p*. The angle S′IO formed by the emergent and incident ray is called the angle of deviation. This angle is no longer susceptible of a maximum, but of a minimum, which varies for each kind of rays, and to which also efficient rays correspond. It is calculated that the minimum angle for violet rays is 54° 7′, and for red rays only 50° 57′; hence it is that the red bow is here on the inside, and the violet arc on the outside. There is a loss of light for every internal reflection in the drop of rain, and, therefore, the colours of the secondary bow are always feebler than those of the internal one. The secondary bow ceases to be visible when the sun is 54° above the horizon.

The moon sometimes produces rainbows like the sun, but they are very pale.

903. **Aurora borealis.**—The *aurora borealis*, or northern light, or more properly *polar aurora*, is a remarkable luminous phenomenon which is frequently seen in the atmosphere at the two terrestrial poles. The following is a description of an aurora borealis observed at Bossekop, in Lapland, lat. 70°, in the winter of 1838–1839.

In the evening, between 4 and 8 o'clock, the upper part of the fog which usually prevails to the north of Bossekop became coloured. This light became more regular, and formed an indistinct arc of a pale yellow, with its concave side turned towards the earth, while its summit was in the magnetic meridian.

Blackish rays soon separated the luminous parts of the arc. Luminous rays formed, becoming alternately rapidly and slowly longer and shorter, their lustre suddenly increasing and diminishing. The bottom of these rays always showed the brightest light, and formed a more or less regular arc. The length of the rays was very variable, but they always converged towards the same point of the horizon, which was in the prolongation of the north end of the dipping needle; sometimes the rays were prolonged as far as their point of meeting, and thus appeared like a fragment of an immense cupola.

The arc continued to rise in an undulatory motion towards the zenith. Sometimes one of its feet or even both left the horizon; the folds became more distinct and more numerous; the arc was now nothing more than a long band of rays convoluted in very graceful shapes, forming what is called the boreal crown. The lustre of the rays varied suddenly in intensity, and attained that of stars of the first magnitude; the rays darted with rapidity, the curves formed and reformed like the folds of a serpent (fig. 745), the base was red, the middle green, while the remainder retained its bright yellow colour. Lastly, the lustre diminished, the colours disappeared : everything became feebler or suddenly went out.

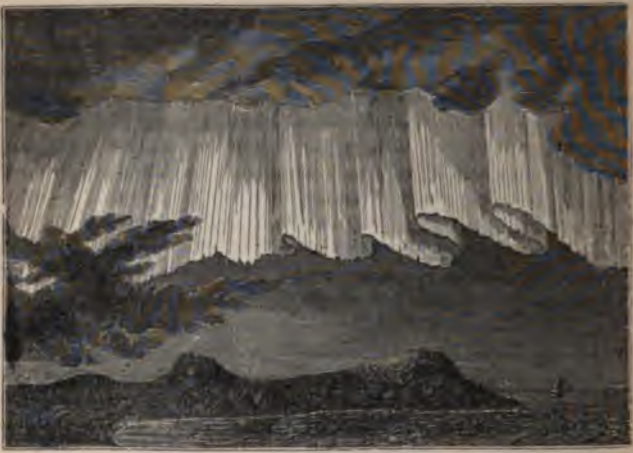


Fig. 745.

A French scientific commission to the North observed 150 auroræ boreales in 200 days; it appears that at the poles, nights without an aurora borealis are quite exceptional, so that it may be assumed that they take place every night, though with varying intensity. They are visible at a considerable distance from the poles, and over an immense area. Sometimes the same aurora borealis has been seen at the same time at Moscow, Warsaw, Rome, and Cadiz.

Numerous hypotheses have been devised to account for the auroræ boreales. The constant direction of their arc as regards the magnetic meridian, and their action on the magnetic needle (650), show that they ought to be attributed to electric currents in the higher regions of the atmosphere. This hypothesis is confirmed by the circumstance observed in France and other countries on August 29 and September 1, 1859, that two brilliant auroræ boreales acted powerfully on the wires of the electric telegraph ; the alarums were for a long time violently rung, and despatches were frequently interrupted by the spontaneous abnormal working of the apparatus.

The spectrum of the aurora borealis has been found by Vogel to consist of five lines in the green, and of an indistinct line in the blue : to which must be added a red line due to the red protuberances ; these lines are the same as those of nitrogen greatly rarefied and at a low temperature.

According to M. de la Rive the auroræ boreales are due to electric discharges which take place in polar regions between the positive electricity of the atmosphere and the negative electricity of the terrestrial globe ;

electricities which themselves are separated by the action of the sun, principally on the equatorial regions.

The occurrence of irregular currents of electricity which manifest themselves by abnormal disturbances of telegraphic communications is not infrequent; such currents have received the name of earth currents. Sabine has found that these magnetic disturbances are due to a peculiar action of the sun, and probably independently of its radiant heat and light. It has also been ascertained that the aurora borealis as well as earth currents invariably accompany these magnetic disturbances. According to Balfour Stewart, auroræ and earth currents are to be regarded as secondary currents due to small but rapid changes in the earth's magnetism; he likens the body of the earth to the magnetic core of a Ruhmkorff's machine, the lower strata of the atmosphere forming the insulator, while the upper and rarer, and therefore electrically conducting strata, may be considered as the secondary coil.

On this analogy the sun may perhaps be likened to the primary current which performs the part of producing changes in the magnetic state of the core. Now in Ruhmkorff's machine the energy of the secondary current is derived from that of the primary current. Thus if the analogy be correct, the energy of the aurora borealis may in like manner come from the sun; but until we know more of the connexion between the sun and terrestrial magnetism these ideas are to be accepted with some reserve.

CLIMATOLOGY.

904. **Mean temperature.**—The *mean daily temperature*, or simply *temperature*, is that obtained by adding together 24 hourly observations, and dividing by 24. A very close approximation to the mean temperature is obtained by taking the mean of the maxima and minima temperatures of the day and of the night, which are determined by means of the maximum and minimum thermometers. These ought to be protected from the solar rays, raised above the ground, and far from all objects which might influence them by their radiation.

The temperatures of a month is the mean of those of 30 days, and the temperature of the year is the mean of those of 12 months. Finally, the temperature of a place is the mean of its annual temperature, for a great series of years. The mean temperature of London is 8·28° C., or 46·9° F. The temperatures in all cases are those of the air and not those of the ground.

905. **Causes which modify the temperature of the air.**—The principal causes which modify the temperature of the air are the latitude of a place, its height, the direction of the winds, and the proximity of seas.

Influence of the latitude.—The influence of the latitude arises from the greater or less obliquity of the solar rays, for as the quantity of heat absorbed is greater the nearer the rays are to the normal incidence (382), the heat absorbed decreases from the equator to the poles, for the rays are then more oblique. This loss is however, in summer, in the temperate and arctic zones, partially compensated by the length of the days. Under the equator, where the length of the days is constant, the temperature is almost invariable; in the latitude of London, and in more northerly countries, where the days are very unequal, the temperature varies greatly; but in summer it sometimes rises almost as high as under the equator. The lowering of the temperature produced by the latitude is small; thus in a latitude of 115 miles north of France, the temperature is only 1° C. lower.

Influence of altitude. The height of a place has a much more considerable influence on the temperature than its latitude. In the temperate zone a diminution of 1° C corresponds in the mean to an ascent of 180 yards.

The cooling on ascending in the atmosphere has been observed in balloon ascents, and a proof of it is seen in the perpetual snows which cover the highest mountains. It is caused by the greater rarefaction of the air, which necessarily diminishes its absorbing power; besides which the air is at a greater distance from the ground, which heats it by contact; and finally dry air is very diathermanous.

The law of the diminution of temperature corresponding to a greater height in the atmosphere has not been made out, in consequence of the numerous perturbing causes which modify it, such as the prevalent winds, the hygrometric state, the time of day, etc. The difference between the temperature of two places at unequal heights is not proportional to the difference of level, but for moderate heights an approximation to the law may be made. As the mean of a series of very careful observations made by Mr. Walsh during balloon ascents, a diminution of 1° C. corresponded to an increase in height of 232 yards.

Direction of winds. As winds share the temperature of the countries which they have traversed, their direction exercises great influence on the air in any place. In Paris, the hottest winds are the south, then come the south-east, the south-west, the west, the east, the north-west, north, and, lastly, the north-east, which is the coldest. The character of the wind changes with the seasons; the east wind, which is cold in winter, is hot in summer.

Proximity of the seas. The neighbourhood of the sea tends to raise the temperature of the air, and to render it uniform. The average temperature of the sea in equatorial and polar countries is always higher than that of the atmosphere. With reference to the uniformity of the temperature, it has been found that in temperate regions—that is, from 25° to 50° of latitude, the difference between the maximum and minimum temperature of a day does not exceed, on the sea, 2° to 3°; while upon the continent this amounts to 12° to 15°. In islands the uniformity of temperature is very perceptible, even during the greatest heats. In continents, on the contrary, the winters for the same latitudes become colder, and the difference between the temperature of summer and winter becomes greater.

906. **Gulf stream.**—A similar influence to that of the winds is exerted by currents of warm water. To one of these, the Gulf stream, the mildness of the climate in the north-west of Europe is mainly due. This

great body of water, taking its origin in equatorial regions, flows through the Gulf of Mexico, from whence it derives its name; passing by the southern shores of North America, it makes its way in a north-westerly direction across the Atlantic, and finally washes the coast of Ireland and the north-west of Europe generally. Its temperature in the Gulf is about 28° C. (and generally it is a little more than 5° C.) higher than the rest of the ocean on which it floats, owing to its lower specific gravity. To its influence is due the milder climate of west Europe as compared with that of the opposite coast of America; thus the river Hudson, in the latitude of Rome, is frozen over three months in the year. It also causes the polar regions to be separated from the coasts of Europe by a girdle of open sea; and thus the harbour of Hammerfest is open the year round. Besides its influence in thus moderating climate, the Gulf stream is an important help to navigators.

907. **Isothermal lines.**—When on a map all the points whose temperature is known to be the same are joined, curves are obtained which Humboldt first noticed, and which he called *isothermal lines.* If the temperature of a place only varied with the obliquity of the sun's rays, that is, with the latitude, isothermal lines would all be parallel to the equator; but as the temperature is influenced by many local causes, especially by the height, the isothermal lines are always more or less curved. On the sea, however, they are almost parallel. A distinction is made between *isothermal lines*, *isotheral lines*, and *isochimenal lines*, where the mean *general*, the *mean summer*, and the *mean winter* temperatures are respectively constant. An *isothermal zone* is the space comprised between two isothermal lines. Kupffer also distinguishes *isogeothermic lines* where the mean temperature of the soil is constant.

908. **Climate.**—By the climate of a place is understood the whole of the meteorological conditions to which a place is subjected; its mean annual temperature, summer and winter temperatures, and by the extremes within which these are comprised. Some writers distinguish seven classes of climates, according to their mean annual temperature: a *hot climate* from 29° 5′ to 25° C.; a *warm climate* from 25° to 20° C.; a *mild climate* from 20° to 15°; a *temperate climate* from 15° to 10° C.; a *cold climate* from 10° to 5°; a *very cold climate* from 5° to zero; and an *arctic climate* where the temperature is below zero.

Those climates, again, are classed as *constant climates*, where the difference between the mean and summer and winter temperature does not exceed 6° to 8°; *variable* climates, where the difference amounts to from 16° to 20°; and *extreme* climates, where the difference is greater than 30°. The climates of Paris and London are variable; those of Pekin and New York are extreme. Island climates are generally little variable, as the temperature of the sea is constant; and hence the distinction between land and sea climates. Marine climates are characterised by the fact that the difference between the temperature of summer and winter is always less than in the case of continental climates. But the temperature is by no means the only character which influences climates; there are, in addition, the humidity of the air, the quantity and frequency of the rains, the number of storms, the direction and intensity of the winds, and the nature of the soil.

909. **Distribution of temperature on the surface of the globe.**—The temperature of the air on the surface of the globe decreases from the equator to the poles; but it is subject to perturbing causes so numerous and so purely local, that its decrease cannot be expressed by any law. It has hitherto not been possible to do more than obtain by numerous observations the mean temperature of each place, or the maximum and minimum temperatures. The following table gives a general idea of the distribution of heat in the northern hemisphere:—

Mean temperatur ferent latitudes.

Ayssinia . . .	31·0°C	ris . . .	10·8° C
Calcutta . . .	28·5	ndon . . .	8·3
Jamaica . . .	26·1	ussels . . .	10·2
Senegal . . .	24·6	asburg . . .	9·8
Rio de Janeiro . .	23·1	neva . . .	9·7
Cairo	22·4	ston . . .	9·3
Constantine . . .	17·2	ckholm . .	5·6
Naples	16·7	Moscow . . .	3·6
Mexico . . .	16·6	St. Petersburg . .	3·5
Marseilles . . .	14·1	St. Gothard . .	−1·0
Constantinople . .	13·7	Greenland . . .	−7·7
Pekin	12·7	Melville Island . .	−18·7

These are mean temperatures. The highest temperature which has been observed on the surface of the globe is 47·4° at Esne, in Egypt, and the lowest is −56·7 at Fort Reliance, in North America; which gives a difference of 104·1° between the extreme temperatures observed on the surface of the globe.

The highest temperature observed at Paris was 38·4° on July 8, 1793, and the lowest −23·5 on December 26, 1798. The highest observed at Greenwich was 35° C. in 1808, and the lowest −20° C. in 1838.

No arctic voyagers have succeeded in reaching the poles, in consequence of these seas being completely frozen, and hence the temperature is not known. In our hemisphere the existence of a single *glacial pole*, that is, a place where there was the maximum cold, has been long assumed. But the bendings which the isothermal lines present in the northern hemisphere have shown that in this hemisphere there are two cold poles, one in Asia, to the north of Gulf Taymour, and the other in America, north of Barrow's Straits, about 15° from the earth's north pole. The mean temperature of the first of these poles has been estimated at −17°, and that of the second at −19°. With respect to the austral hemispheres, the observations are not sufficiently numerous to tell whether there are one or two poles of greatest cold, or to determine their position.

910. **Temperatures of lakes, seas, and springs.**—In the tropics the temperature of the sea is generally the same as that of the air; in polar regions the sea is always warmer than the atmosphere.

The temperature of the sea under the torrid zone is always about 26° to 27° at the surface; it diminishes as the depth increases, and in temperate as well as in tropical regions the temperature of the sea at great depths is between 2·5° and 3·5°. This temperature of the lower layers is caused by submarine currents which carry the cold water of the polar seas towards the equator.

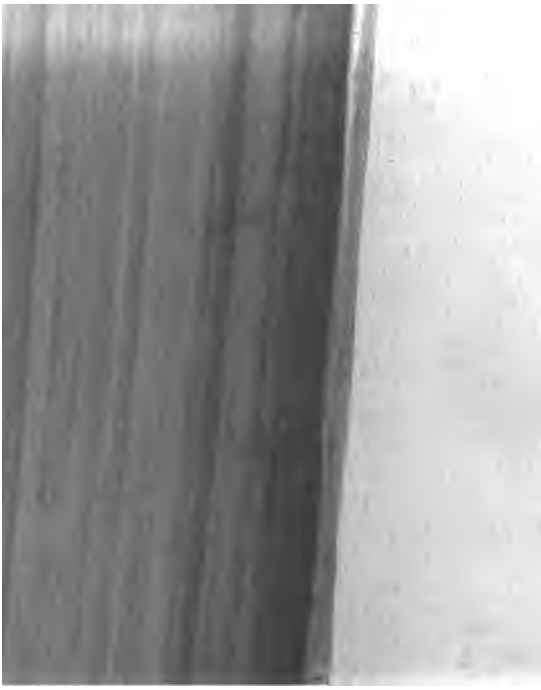
The variations in the temperature of lakes are more considerable; their surface, which becomes frozen in winter, may become heated to 20° or 25° in summer. The temperature of the bottom, on the contrary, is virtually 4°, which is that of the maximum density of water.

Springs which arise from rain water which has penetrated into the crust of the globe to a greater or less depth necessarily tend to assume the temperature of the terrestrial layers which they traverse. Hence when they reach the surface their temperature depends on the depth which they have attained. If this depth is that of the layer of invariable temperature, the springs have a temperature of 10° or 11° in this country, for this is the temperature of this layer, or about the mean annual temperature. If the springs are not very copious, their temperature is raised in summer and cooled in winter, by that of the layers which they traverse in passing from the invariable layer to the surface. But if they come from below the layer of invariable temperature, their temperature may considerably exceed the mean temperature of the place, and they are then called *thermal springs.* The following list gives the temperature of some of them:

Wildbad	37·5° C.
Vichy	40
Bath	46
Ems	56
Baden-Baden	67·5
Chaudes-Aigues	88
Trincheras	97
Great Geyser, in Iceland, at a depth of 66 ft.	124

From their high temperature they have the property of dissolving many mineral substances which they traverse in this passage, and hence form *mineral waters.* The temperature of mineral waters is not modified in general by the abundance of rain or of dryness; but it is by earthquakes, after which they have sometimes been found to rise and at others to sink.

911. **Distribution of land and water.**—The distribution of water on the surface of the earth exercises great influence on climate. The area covered by water is considerably greater than that of the dry land; and the distribution is unequal in the two hemispheres. The entire surface



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